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ADVANCED ROTORCRAFT TECHNOLOGY

TASK FORCE REPORT
OCTOBER 15, 1978

NASA

National Aeronautics
and Space Administration

ADVANCED ROTORCRAFT TECHNOLOGY
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EXECUTIVE SUMMARY

INTRODUCTION

In early 1978 a special Rotorcraft Task Force was created by the Office of Aeronautics and Space Technology (OAST). This Task Force, made up of representatives of NASA, DOD, and FAA, was constituted to determine the technological needs and opportunities related to future civil and military rotorcraft, and to prepare a program plan for NASA research which was responsive to the needs and opportunities. Estimates of the total funding levels that would be required to support the proposed program plan are also included.

TECHNOLOGY PLAN

The Task Force reviewed needs and opportunities in all areas of rotorcraft technology. Inputs were solicited from airframe and engine manufacturers, operators, NASA research centers, and other government agencies. As a result of these inputs and a series of program plan iterations, four major program elements were defined. These advanced rotorcraft technology elements were aerodynamics and structures, flight control and avionic systems, propulsion, and vehicle configurations. Each of these elements was broken into two or more specific areas of emphasis. In general, the program plan places the primary emphasis on design methodology where the development and verification of analytical methods is built upon a sound data base.

Aerodynamics and Structures

The Task Force defined programs to improve and develop design methodology in key areas of aerodynamics, structural dynamics, acoustics and advanced materials applications which cannot be adequately covered within the current ongoing research effort in aeromechanics and rotor systems.

Aero/Acoustics. The first program phase provides for systematic small and large scale tests of a rotor family and a complete helicopter configuration with heavy emphasis on detailed flow, acoustic and aerodynamic parameter measurements and the development of improved analytical prediction methods. The later phases involve the use of design methodology to design and predict the performance and noise

characteristics of specific second generation rotors, followed by testing to check out the prediction and to update the methods, as may be required.

Vibration Reduction. The first phase concentrates on airframe loads and structural modeling methodology. An industry/government team approach will be utilized to assist in generating more widely acceptable and useable prediction and modeling methods. Program elements related to the vibration prediction methodology include in-service flight load measurements during civil helicopter operations, and use of active controls to suppress vibration, and internal noise reduction. Later phases of the program address use of advanced materials and advanced structural and aeroelastic concepts in hub/blade design methodology.

Composite Airframe. This program element includes composite fuselage design studies and associated experimental assessment of critical design features, particularly related to high curvature and highly loaded elements. The second phase consists of build-up and thorough ground-based testing of a major fuselage component such as a center section or upper fuselage assembly.

Flight Control and Avionic Systems

There are increasing demands and opportunities for rotorcraft flight control and avionic systems to provide improved performance, efficiency, reliability, and handling qualities; pilot workload improvements; vibration reduction; and noise reduction. To help realize this potential the Task Force defined two research elements which focus on fully integrated systems designs that properly interrelate rotor, propulsion, airframe/structure, and flight control avionic systems.

All-Weather Rotorcraft. Systems concepts will be defined, constructed and evaluated through simulations, controlled flight research under highly instrumented conditions and operational flight assessments. There are two main all-weather rotorcraft systems technology thrusts. These are remote site "on-board" systems technology and high density 3D/4D guidance, including air traffic control interfacing and integrated Category III systems technology.

Active Control Technology. Two main task areas will be addressed. These are full-authority vehicle systems and mission capability improvement. Full authority systems technology will emphasize the design, evaluation and validation of flight critical, full authority concepts typically associated with fly-by-wire, fly-by-light and control configured vehicle technology. In regard to mission capability improvements, primary emphasis will be placed on the design and validation of "local area," high precision, low altitude, fast response guidance and navigation system technology.

Propulsion

Three program elements were defined which are responsive to the needs of the rotorcraft manufacturing community and the users, both civil and military. The major emphasis is on improved durability and maintenance characteristics of rotorcraft propulsion systems, including small engines.

Engine Component Design Methodology. Analytical design techniques will be established using both computational and experimental methods. Parametric experiments will be conducted to develop a strong empirical data base for single stage axial and centrifugal compressor stages. Effects of unsteady flow and turbulence on vane and blade heat transfer will also be studied. A study will be conducted to establish the critical design criteria for small turbine engine combustors. In addition, full-authority digital electronic control components will be evaluated in terms of high reliability and low cost. In the area of diagnostics, maintenance records of rotorcraft users and engine manufacturers will be evaluated to identify the most prevalent causes of failure or reasons for removal of rotorcraft propulsion system components.

Power Transfer Technology. Four key technology task areas were defined. In the noise and vibration task area emphasis will be on obtaining a fundamental understanding of sources, and development of analytical prediction techniques and design concepts for noise and vibration reduction. Diagnostics will be addressed in a similar manner as the engine diagnostic effort mentioned above. Manufacturer and user records will be evaluated, and selected components will be "tracked" during in-service operation. Sensors and displays will also be developed and evaluated in system condition monitoring studies. A major task emphasis will also be on

identifying, developing, and proof-of-concept demonstrations of advanced power transfer components and systems.

Systems Integration. Systems condition monitoring will be addressed through the application of advanced technology sensors for detecting such internal factors as gas, metal, and lubricating oil temperatures in critical locations throughout in-service propulsion systems. This data, from a variety of vehicle and mission types, will be used to develop analytical models for predicting the life history of critical components. Various methods of augmenting engine power will be analytically evaluated. Innovative techniques will be sought and experimentally explored to define technological capabilities. A complete engine/electronic control/transmission system will be assembled and experimentally evaluated in a ground test facility. Improved engine inlet and separator aerodynamics and ice protection will be evaluated in scale model tests.

Vehicle Configurations

A research plan was defined which is aimed at establishing a technology base in high speed and large rotorcraft concepts. The overall approach is to start with concept evaluations using existing vehicles and conducting ground based testing and studies of advanced systems and concepts.

High Speed Concepts. Ongoing proof-of-concept flight tests of the XV-15 Tilt Rotor Research Aircraft will be extended to acquire a thorough documentation of tilt rotor aerodynamics, flying qualities, stability and control and structural loads characteristics. A similar program will be carried out on the Advancing Blade Concept (ABC) vehicle as a follow-on to the current Army/Navy/NASA program. Additional preliminary design studies, scale model tests, and simulation studies of other promising high speed concepts will also be conducted.

Large Rotorcraft Concepts. A broad range of large rotorcraft concepts and configurations will be evaluated through concept studies, ground based testing and flight testing of available hardware. The initial effort will involve the assessment of various options for heavy lift, cargo and transport missions. A key consideration of the heavy lift studies will be the feasibility of providing

a high speed ferry capability for heavy lift vehicles. The large rotorcraft program plan includes the ground based testing of the XCH-62A transmission system to provide a technical data base on large drive systems for future civil and military heavy lift, cargo and transport vehicles.

RESOURCES

The ten-year plan discussed above was defined in phases. The R&D cost over a ten year period of all elements is estimated at about $398 million (FY78 dollars).

ADVISORS

In developing these plans the Rotorcraft Task Force has interacted frequently with the airframe and engine manufacturers as well as users. The plan has been reviewed at least once by each of the following:

(a) An Ad Hoc Committee on Rotorcraft technology specially constituted for the purpose by the National Research Council Aeronautics and Space Engineering Board.

(b) NASA Aeronautical Advisory Committee.

(c) Management Council of the Office of Aeronautics and Space Technology.

The plans presented herein reflect the counsel received from these advisors.

The Task Force recommendations are now being reviewed and evaluated by NASA as part of the normal budget development cycle.

INTRODUCTION

The helicopter industry is approximately 40 years old, the first production designs originating in the early 1940's. The major trends in the growth of the industry and the state of technology (Figure I-1) have brought this industry to a position of major world importance and maturity. While the prime mover in this development has been military utilization, the civil use of the helicopter's unique capability is now serving as a growing catalyst to future development.

The current magnitude of the world market potential has stimulated aggressive competition among the world's helicopter manufacturers (Figure I-2). Currently, the U.S. position as free world leader is being effectively challenged by foreign designers. The key to this challenge is the innovative application of advanced technology to achieve significantly improved vehicles with higher reliability, reduced cost of ownership, and increased operational capability.

NASA, with unique aeronautical research capabilities, can make a significant contribution to advancing the state of technology readiness in the U.S. In recognition of this potential, the Office of Aeronautics and Space Technology created a special Rotorcraft Task Force to: (1) conduct a review and assessment of rotorcraft technology needs, (2) assess the ongoing NASA rotorcraft program, and (3) recommend an appropriate plan to assure that NASA's unique capabilities are used effectively in meeting the nation's rotorcraft technology needs over the next ten years.

The Task Force, with the valuable assistance of the industry and with guidance and oversight by a special ad hoc Committee on Rotorcraft Technology of the Aeronautics and Space Engineering Board, has prepared a proposed Advanced Rotorcraft Technology Program recommendation for consideration. This document outlines the planning activity, advocacy, and elements of a ten year program.

In terms of the overall plan, the final formulation and any future implementation of such a program would be the product of the normal budget review process involving both executive branch and congressional review of specific program proposals in the context of national goals and priorities.

NASA is currently evaluating the Task Force recommendations to determine how and to what extent the initial phases of the proposed program will be supported. Subsequent fiscal year funding will be determined in the budget development process and will be subject to an overall assessment of budget priorities.

ROTORCRAFT STATUS

MAJOR TRENDS

1940-1950	1950-1970	1970-PRESENT	PRESENT	FUTURE
• FIRST FLIGHT	• TURBINIZED	• TOTAL ARMY COMMITMENT	• CIVIL USE ACCELERATES	• STRONG FOREIGN COMPETITION
• MILITARY USE INITIATED	• INCREASED USE IN KOREA	• NASA-ARMY LABS	• FOREIGN INDUSTRY AGGRESSIVE	• CONTINUED CIVIL NEED, GROWTH
	• CIVIL USE STARTS	• CIVIL USE GROWS	• MILITARY DESIGNS PRESSED UTTAS, AAH	• NEW CIVIL AND MILITARY DESIGNS REQ D

STATE OF TECHNOLOGY

• TECHNOLOGY BASED ON AUTOGYRO AND FIXED WING	• AVAILABLE TECHNOLOGY PRESSED BY INCREASING MISSION REQUIRE-MENTS	• TECHNOLOGY DEVELOPED ON AD HOC BASIS BY INDUSTRY IR&D AND SR&T	• TECHNOLOGY RESERVOIR EXPENDED ON NEW MILITARY AND CIVIL DESIGNS IN U S	• NEED TO TIE NASA R&T TO INDUSTRY APPLICATION
• NACA PLAYS KEY ROLE	• NACA, NASA RESPONSE TO NEEDS SLOWS	• NASA FUNDS FOR RSRA AND TRRA	• FOREIGN TECHNOLOGY GROWING RAPIDLY	• NASA FOCUS ON CIVIL TECHNOLOGY NEEDS AND MIL SUPPORT

FIGURE I-1

BASIS FOR ROTORCRAFT EMPHASIS:

- MAGNITUDE OF WORLD MARKET
- FOREIGN THREAT IN CONTESTED MARKET
- CIVIL AND MILITARY USE GROWTH
- HIGH PAYOFF IN APPLICATIONS OF ADVANCED TECHNOLOGY
- NASA IN POSITION TO MAKE SIGNIFICANT TECHNOLOGICAL CONTRIBUTIONS

FIGURE I-2

CIVIL APPLICATIONS

The growth of all sectors of aviation in the past half-century has been dramatic, particularly in the United States. The growth in the "rotary wing" or "rotorcraft" sector of aviation has generally lagged that of conventional or "fixed-wing" aircraft by 20 to 30 years, primarily because of the greater difficulty in initially achieving controlled vertical flight, and the reliance on design evolution by experimenting with modest incremental departures from proven designs. During the last decade significant improvements have been made in the helicopter as a result of R and D investments made by industry and the government. During this same period the national civil benefits from the application of rotorcraft have grown at a signficant rate. A list of the key civil applications is shown in Figure II-1.

Air Transportation

In the area of air transportation (Figure II-2), corporate/business rotorcraft represent a growing segment. Here, a key transportation consideration is the value that the traveler places on his/her time. In the current transportation market, ground transport modes perform adequately for short ranges (10 to 30 miles) and fixed-wing aircraft do an excellent job over 200-400 miles but there exists an ill-defined mid-range where neither is entirely satisfactory. The helicopter is a growing mode of transportation for this region. In special applications where the traveler's time has quantifiable value such as with corporate executives, the helicopter is proving to be extremely successful with better than 20-percent per year growth rates. It is anticipated that air taxi operations, as well as air carrier operations, will grow significantly in the next decade and the ranges over which rotorcraft will be able to compete successfully will extend beyond the present 200 nm stage length.

In the future, the helicopter will grow in value as a tool to permit industry to move out of high cost areas into areas where facilities investment and overhead and land costs are lower, and still maintain key management and customer services. Air taxi operations will grow to serve these special transportation needs. Scheduled helicopter service is dependent, however, on

(1) aggressive, innovative operators, (2) resumption of 1968 growth rates in major hub congestion, (3) availability of latest technology equipment and (4) a substantial reduction in direct operating cost and cost of ownership. By accelerating the development of quiet, economical, all-weather, extended range vehicles with an emphasis on improved reliability and reduced costs, it is anticipated that civil rotorcraft air transportation will grow significantly from the present 2200 helicopters to 3500 by 1985, with this growth continuing through 1990. Benefits in time savings, congestion relief, improved urban transportation and more efficient use of available real estate can result by shifting toward heliports and away from more land intense transportation systems.

Forestry and Agriculture

Helicopters have made a substantial contribution to forest management and agriculture in recent years (Figure II-3). As timber costs have risen, it has become cost effective for timberland owners and managers to invest in complete forest management technology and techniques from seeding new crops to providing insect and disease protection for young trees. Helicopters perform these tasks more efficiently than ground equipment and more precisely than their fixed wing counterparts. The Forest Service alone employs over 140 helicopters to assist in forest firefighting, often because no other means can be effectively used.

Helicopter use in harvesting timber is a small but growing activity accounting for approximately two percent of all logging. With the use of the helicopter, inaccessible forests are being harvested without environmental damage. Discrete logging is now feasible without environmental damage and will grow with the use of the helicopter. This scenario represents the present situation with the future scenario projected to grow significantly at about 12 percent per year.

Helicopters are projected to make significant in-roads into the agricultural aviation market in the future with a projected growth rate in excess of 15-percent per year. Helicopters comprise 10-percent of the total agricultural fleet but accomplish 20 percent of the agricultural work, primarily because of higher turn rates, and the ability to land on top of support trucks or onsite for refueling and reloading.

Resource Exploration/Development

Most of the world's reserves of natural resources are in remote areas, which are generally inaccessible or poorly accessible by use of ground transportation. This applies whether it is a coal field in the Appalachians, an oil field in a South American jungle, or a drill rig in the Gulf of Alaska. Without the helicopter, man's recovery of these reserves would be much more difficult, if not impossible.

By 1985, 50-percent of the world's petroleum needs will most likely come from off-shore sources such as those tracts off the coasts of Massachusetts, Rhode Island and New Jersey.

The helicopter is a vital link in the search for, and production of oil (Figure II-4). It is used for delivering men and equipment to off-shore rigs, constructing and servicing pipelines in remote areas, and moving entire drill rigs in otherwise inaccessible areas. Two hundred and thirty thousand passengers are transported each month in the Gulf of Mexico and 80,000 passengers are transported in the North Sea. If all operations shift to one week turnaround for the crews and predicted growth is realized, passenger transportation worldwide will be over a million passengers per year by 1985 with average stagelengths doubling to over 200 nautical miles. All aspects of the multi-billion dollar oil industry as expensive and every hour saved through helicopter operations means savings of thousands of dollars in rig costs and manhour expense. While used primarily for transporting workers at present, large helicopters that can move whole drilling towers could save as much as $40,000 a day in crane rental costs alone when they become available. Regardless of their acquisition and operating costs, use of helicopters will continue to grow in this important application.

Mining is also one of the fastest growing recent markets for helicopters. In 1974 six mining companies employed helicopters; in 1977, 85 companies are using helicopters.

Construction

Helicopters are used in 50-percent of the powerline construction in Canada and in 10-percent of the powerline construction in the U.S. The potential for reducing the costs of installing heavy equipment is significant. Where

mobile cranes are required, use of helicopters costs half that of conventional methods and takes 1/20 of the time.

Conventional major construction methods will be around for a long time, but more and more contractors are turning to helicopters for special one-shot tasks because they save both time and money (as illustrated in Figure II-5). If a task is one of a repetitive nature, then chances are the set-up time and costs on a conventional crane are cost effective. However, when a task is of limited duration or involves movement of materials from a remote staging area, then the helicopter is the more cost-effective choice. Requests are often received by operators to move loads as large as 60,000 pounds, which is not within the present operational vehicle capability.

Public Service

As indicated in Figure II-6 there are a wide variety of public service missions. The first public service helicopter mercy mission was flown in 1945. Since that time it is not possible to count the number of lives that have been saved or accurately estimate the value of lives saved to the nation. One estimate (AIA) is that for every helicopter built in the free world, seven lives have been saved. For example, 400 trapped survivors were rescued by helicopter from the flame-engulfed 25-story Androus building in downtown Sao Paulo, Brazil, in 1972. Ground based rescue equipment cannot be used above the fifth floor; consequently, many city codes now require a rescue heliport on the roofs of buildings over five stories high. During the 1971 Los Angeles quake, helicopters were the only vehicles that initially could get in and out of the demolished area. During the Tampico flood in 1955, military helicopters alone transported 9262 people to safety. Often, only the helicopter can do it in time.

More than 65 cities and 20 states use helicopters for police work because of the improved response time and surveillance capabilities, compared to ground units. In addition, more and more communities are sponsoring emergency medical care services based on helicopter ambulance service. One of the most serious problems that confronts the medical profession today is the lack of easy delivery of emergency health care to minimize "trauma" (injuries and attendant shock) from accidents of all types. It is the fourth largest cause of death in the United States (115,000 persons annually). Helicopter teams with

heliports at trauma centers are now being supported by many states. Consequently, the number of heliports at hospitals has grown rapidly over the last 5 years and it is estimated that in the time period of 1980-1985, 650,000 patients will be carried each year.

Cargo Distribution

The primary consideration of the helicopter in a cargo distribution application is for ship loading/unloading, although with the advent of larger helicopters, railroad car shifting and trailer movement are other potential uses, as illustrated in Figure II-7.

Helicopters have been utilized extensively by the military for supplying field units from fixed bases and occasionally from ships. In civil applications, however, they have been used only under special conditions for ship to shore cargo distribution, primarily in the Middle East where large numbers of ships bringing industrial goods saturated port facilities causing several months' delays. In these circumstances the helicopter has proven to be very successful.

The helicopter offers several advantages over conventional port facilities: (1) ships can lay out, thus avoiding possible collisions in dangerous port facilities; (2) ships can offload while underway, thus making mixed destination cargo more practical; (3) cargo can be transported directly to final destination or to outlying staging areas away from congested port storage facilities; and (4) areas without adequate protected anchorage and port facilities can be opened up to shipping.

Civil Growth

During the past decade, as a result of the recognition of the unique roles that the rotorcraft can play, this versatile class of aircraft has seen very rapid development for both civil and military application. Thus, whereas in 1965 the average production rate for civil rotorcraft in the United States was approximately 300 units, by 1975 the number had reached 800 units and it is expected to exceed 1,000 units by 1980. Total employment in the industry declined somewhat after Vietnam, but increased civil production and use has picked up some of the slack and total employment should approach 50,000 by 1980.

The continued growth of the civil rotorcraft industry appears assured based on the actual growth rates experienced in the 1970's and the solid opportunities that exist. Figure II-8 shows the conservative growth projection for the number of aircraft, heliports, and operators in North America over the next 10 years. Similar trends projected for worldwide growth suggest a very active and competitive future for the world helicopter industry.

FUTURE DIRECTIONS — CIVIL APPLICATIONS

- AIR TRANSPORTATION
- FORESTRY PROTECTION/MANAGEMENT
- AGRICULTURE
- RESOURCES EXPLORATION/DEVELOPMENT
- CONSTRUCTION
- PUBLIC SERVICE AND RESCUE
- CARGO DISTRIBUTION

FIGURE II-1

FUTURE DIRECTIONS — AIR TRANSPORTATION SYSTEMS — SCENARIO CONSIDERATIONS

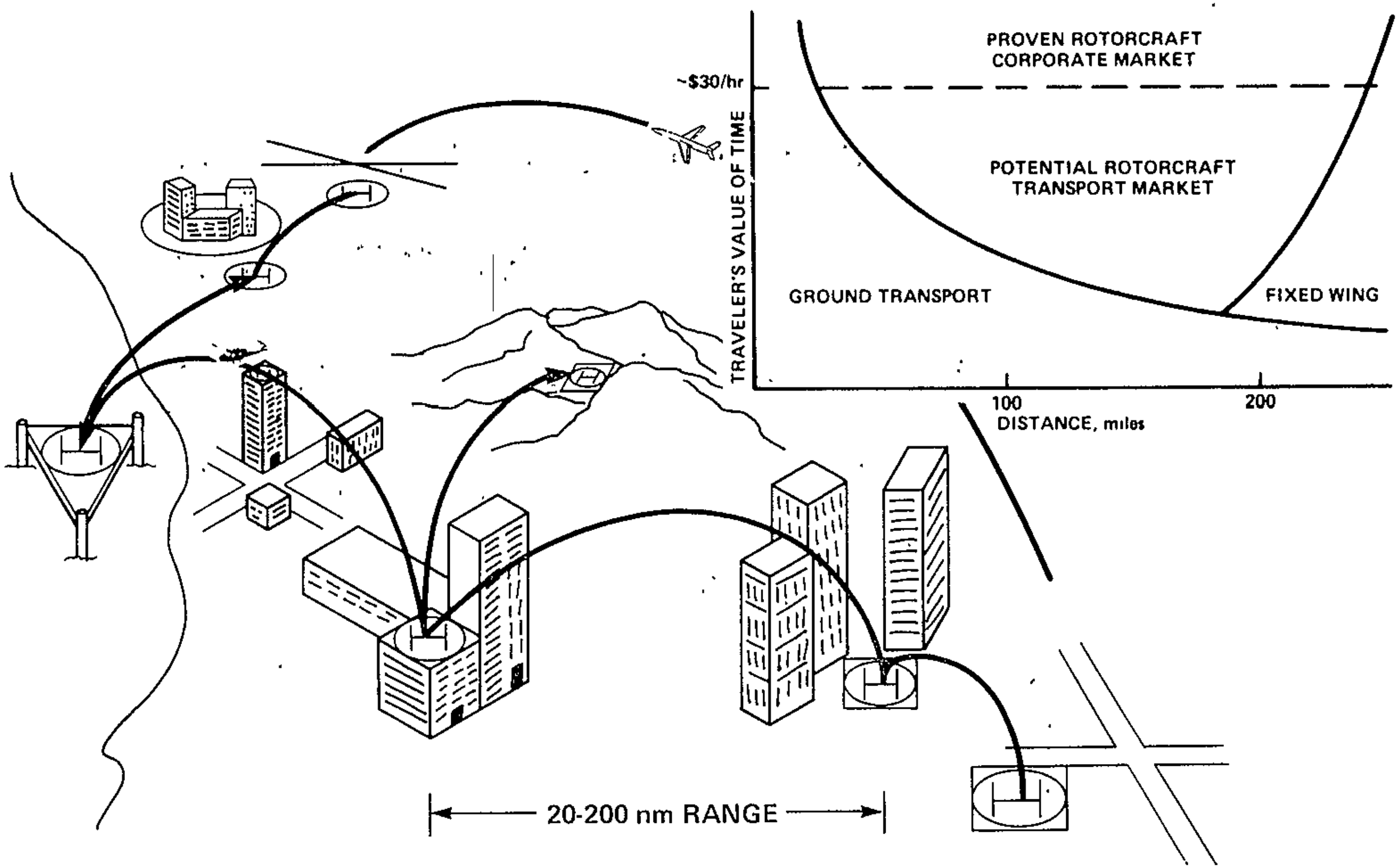
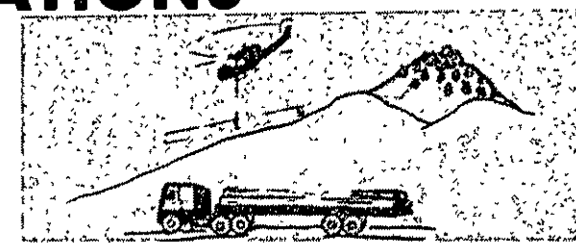


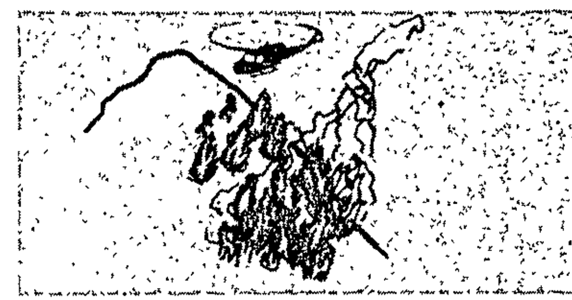
FIGURE II-2

FUTURE DIRECTIONS — FOREST PROTECTION/MANAGEMENT — SCENARIO CONSIDERATIONS



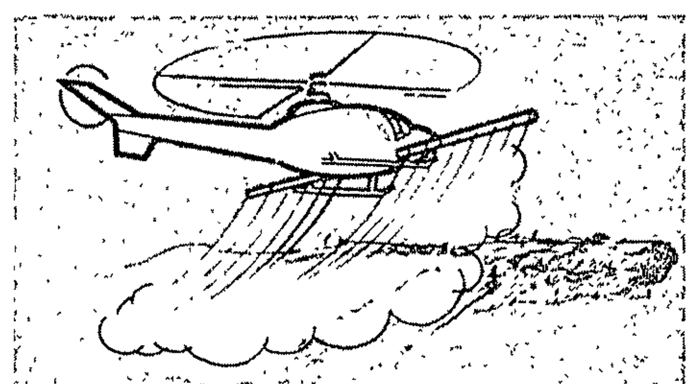
FOREST MANAGEMENT

LOGGING ~ 22 OPERATORS* – 120 HELICOPTERS*



FIRE CONTROL ~ 120 OPERATORS* – 480 HELICOPTERS*
2000 FIRES/YEAR

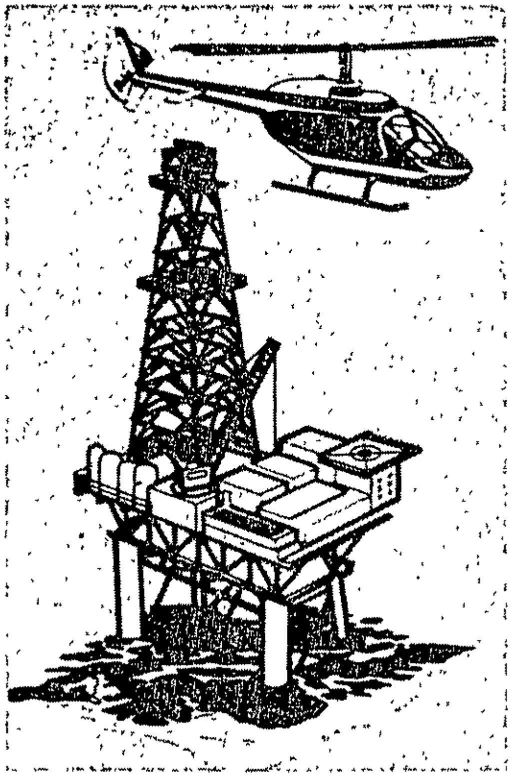
GENERAL FORESTRY (SEEDING, SPRAYING, ETC.) ~ 150 OPERATORS* – 520 HELICOPTERS*



*FULL OR PART-TIME ESTIMATES

FIGURE II-3

FUTURE DIRECTIONS — RESOURCES EXPLORATION/DEVELOPMENT — SCENARIO CONSIDERATIONS



OIL/GAS — MAJOR SCENARIO (GULF EXAMPLE)

HELICOPTERS PLAY A MAJOR ROLE IN THE NATION'S CONTINUING ENERGY SEARCH BY PROVIDING THE ONLY FEASIBLE MEANS OF REACHING OFF-SHORE OIL WELLS. GULF OF MEXICO: 12,182 WELLS, 420 HELICOPTERS 230,000 PASSENGERS/MONTH.

PETROLEUM INDUSTRY PROJECTED TO EXPEND OVER 6+ BILLION DOLLARS OVER NEXT DECADE ON HELICOPTERS AND HELICOPTER SERVICES

MINING — MINOR SCENARIO

1974: 6 MINING COMPANIES USED HELICOPTERS
1977: 85 MINING COMPANIES USED HELICOPTERS

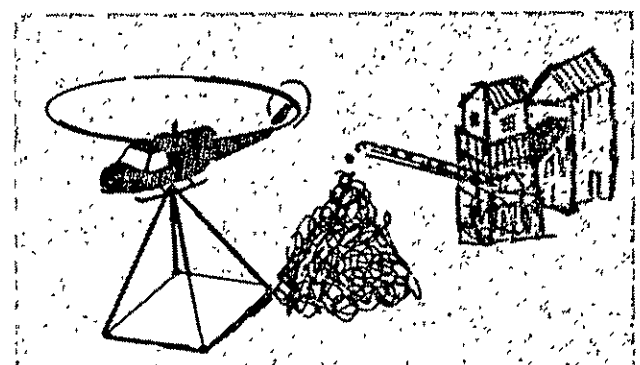
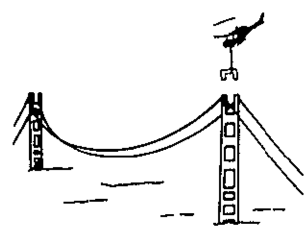


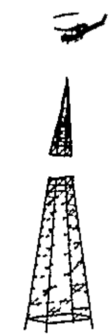
FIGURE II-4

FUTURE DIRECTIONS — CONSTRUCTION — SCENARIO CONSIDERATIONS



HELICOPTER CONSTRUCTION COST SAVINGS
(EXAMPLE)

TASK – MOUNT 19 AIR CONDITIONERS ON ROOF
- HELICOPTER 1½ HRS @ $400 = $600.00
- MOBILE CRANE 3 DAYS @ $480 = $1440.00



TRANSMISSION LINE CONSTRUCTION
(AVERAGE YEARLY)

	TOTAL (MILES)	HELICOPTER PARTICIPATION
U.S.	10,000	1000
CANADA	2000	1000

FIGURE II-5

FUTURE DIRECTIONS — PUBLIC SERVICE ROTORCRAFT SCENARIO CONSIDERATIONS

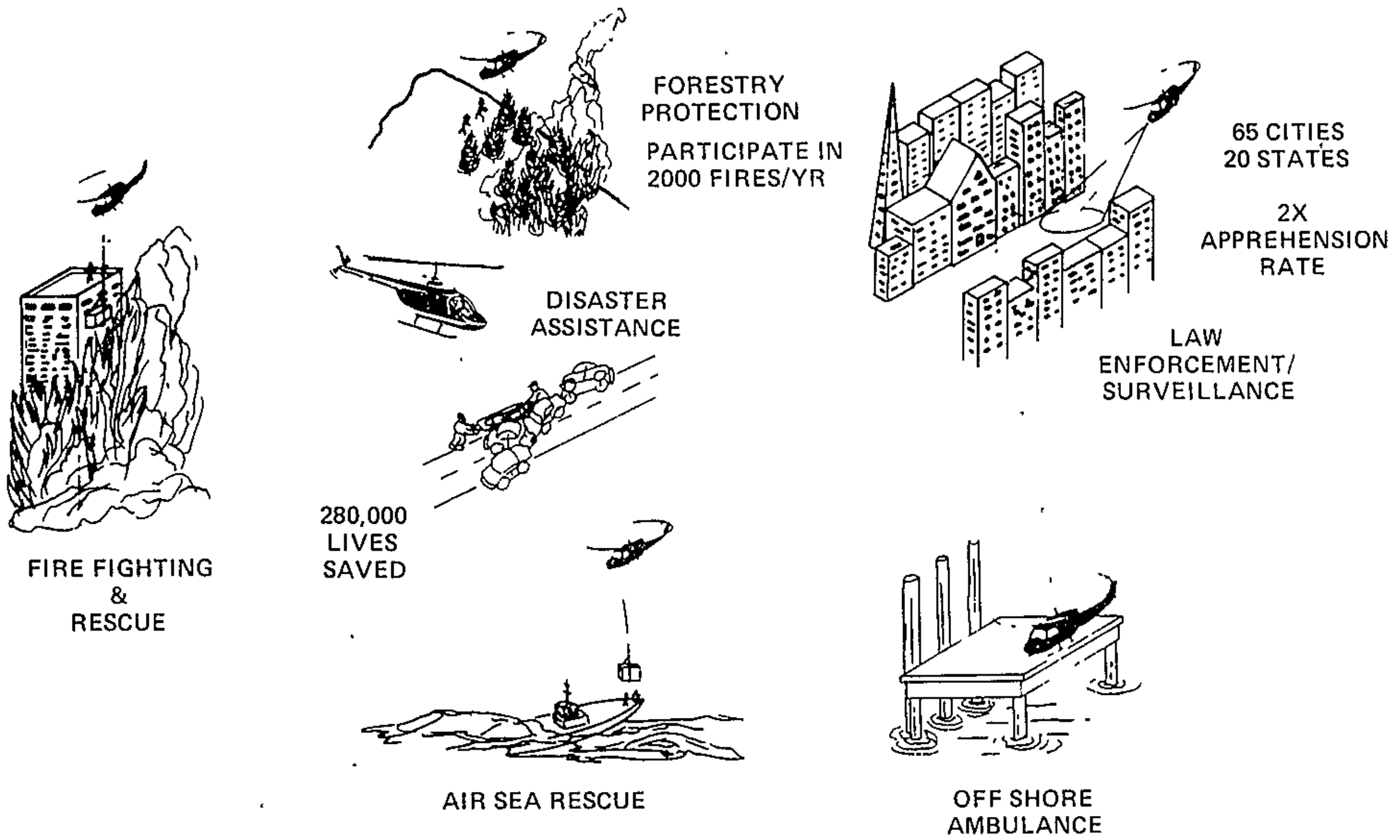
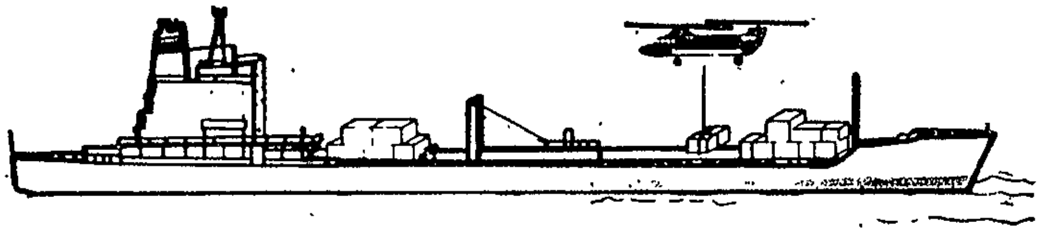
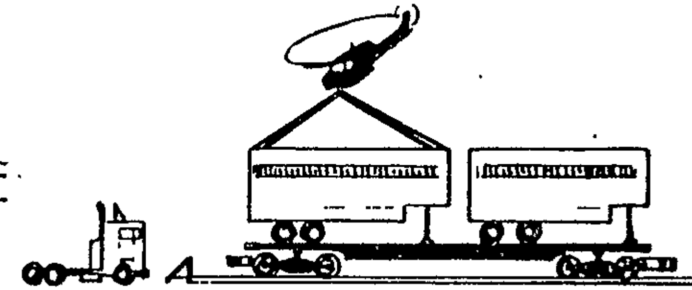


FIGURE II-6

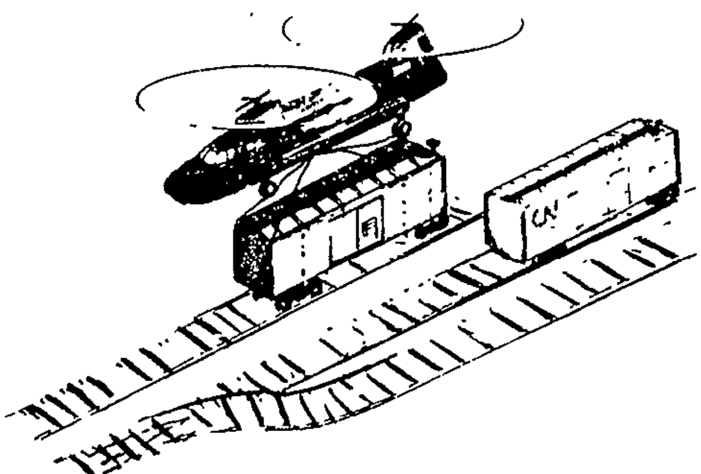
FUTURE DIRECTIONS — CARGO DISTRIBUTION SCENARIO CONSIDERATIONS



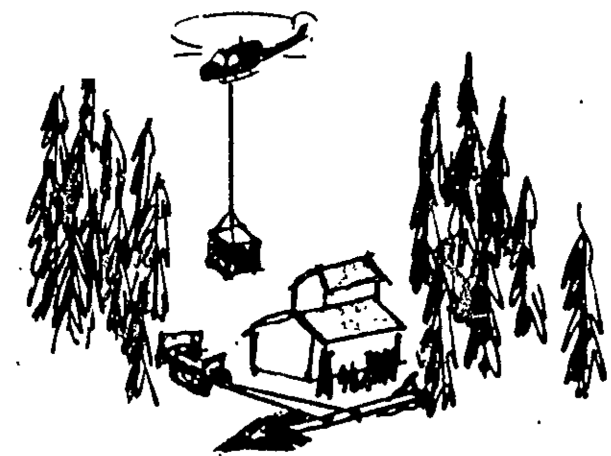
SELF CONTAINED SUPER TANKER
CONTAINER SHIP
LOADING/UNLOADING



TRAILER MOVEMENT



RAILCAR TRANSFER



REMOTE AREA SUPPLY

FIGURE II-7

ROTORCRAFT GROWTH —
AIRCRAFT/HELIPORTS/OPERATORS

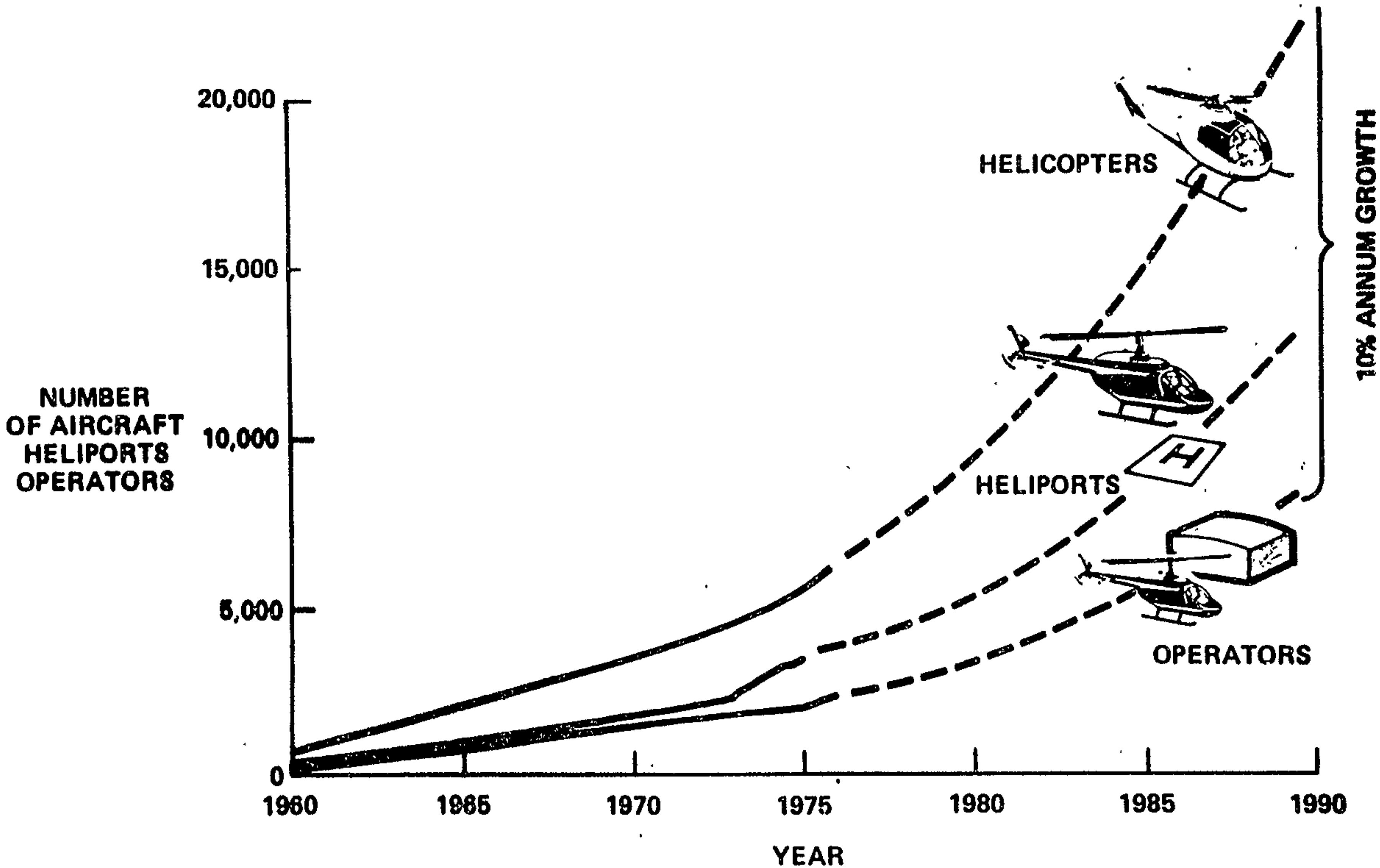


FIGURE II-8

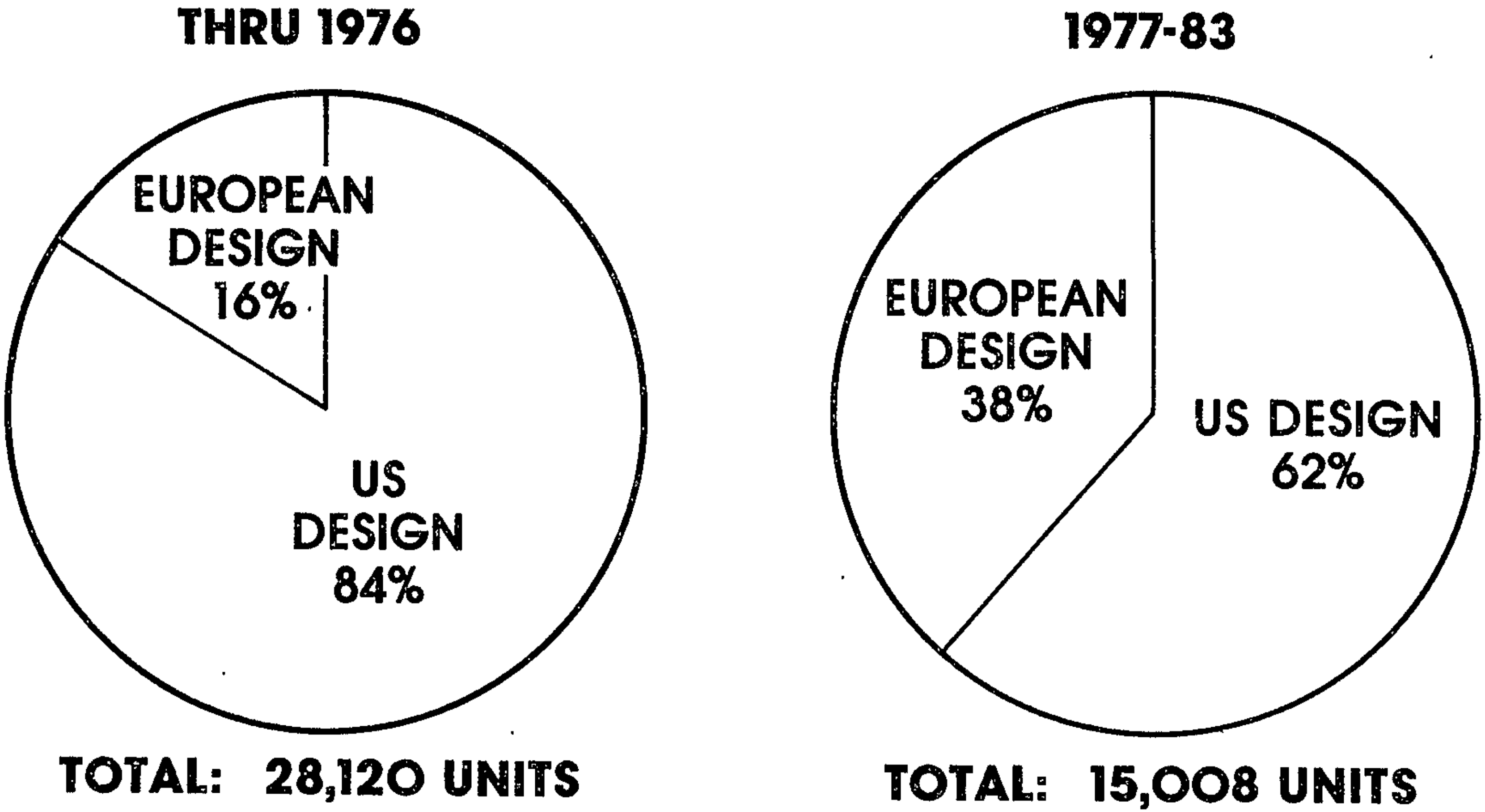
FOREIGN MARKET

In light of the current and anticipated growth in the free world helicopter market there is considerable activity in the U.S. and European industry. There are basically eight helicopter manufacturers capable of developing and producing large volume sales vehicles. The four in the U.S. are Bell Helicopter Textron, Boeing-Vertol, Sikorsky, and Hughes. The European manufacturers are Aerospatiale, Westland, Agusta, and Messerschmitt-Boelkow-Blohm. Figure III-1 illustrates an early U.S. maturity and capability which, in terms of sales, has resulted in the U.S. designs capturing 84 percent of the free world market. Looking ahead to the next five years indicates the U.S. designs will account for 62 percent of the free world sales. This slippage is due to aggressive development programs and sales of European models, and the rapid acceleration of worldwide civil sales opportunities that are exceeding the military market. In addition, the growing acceptance of the helicopter has made it an attractive product for other countries to consider producing for regional markets. Countries which have, or soon will have, production capability through license agreements are growing steadily. They include India, Brazil, Romania, Switzerland, Indonesia, Yugoslavia, Japan, Iran, Taiwan, Australia, South Korea, Pakistan, Argentina, Poland, Israel, and the Phillippeans. In addition, South Africa is developing an experimental autogyro vehicle.

Although the worldwide helicopter production has now passed $2 billion per year, Figure III-2 shows U.S. exports in dollar value have actually decreased. On the other hand, U.S. imports of foreign helicopters have grown impressively. Aerospatiale, alone, comprises 11.6 percent of the overall U.S. civil market, up from 4.6 percent in 1976.

The attraction of the European helicopter seems to be the innovative way in which new technology is applied. The Astar 350, for example, combines glass fiber blades, semi-composite hub, and elastomeric bearings in the main and tail rotors - all of which reduce operation and maintenance costs. Aggressive efforts are also being made to reduce weight and simplify production methods by applying advanced materials.

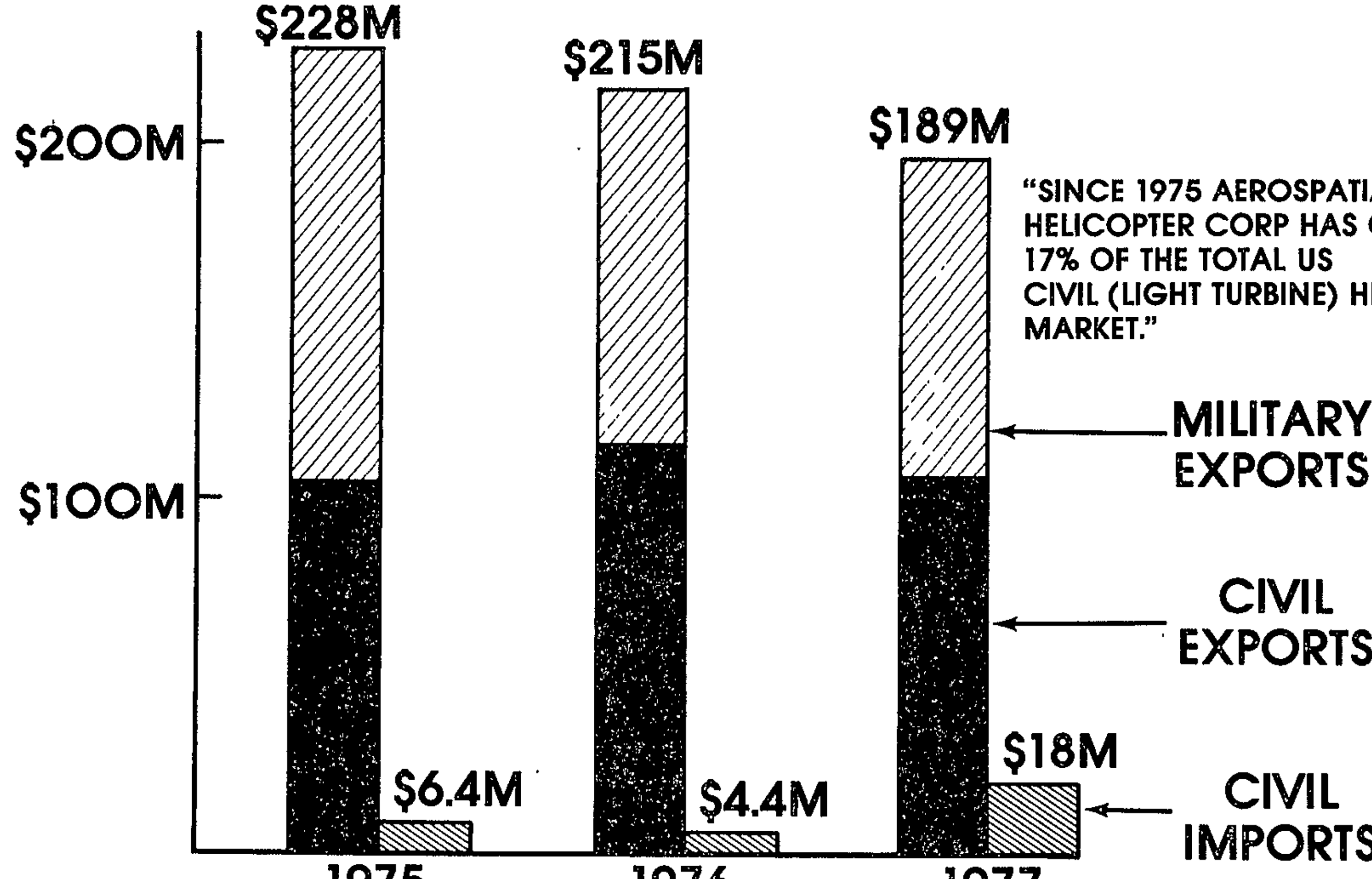
FREE WORLD HELICOPTER PRODUCTION
PAST AND FORECAST



SOURCE: FORECAST ASSOCIATES

FIGURE III-1

US HELICOPTER EXPORT & IMPORT DATA
1975-77



SOURCE: AVIATION WEEK, JULY 3, 1978

FIGURE III-2

NASA ORGANIZATION AND PLANNING ACTIVITY

A number of key factors associated with the current NASA organizational, management, and financial posture relate directly to the development of the proposed Advanced Rotorcraft Technology Program. Some of these factors are discussed below.

NASA Organization and Capabilities

The NASA organizational structure related to rotorcraft technology is shown in Figure IV-1. Three NASA Centers are involved. Ames Research Center has been designated lead center for rotorcraft research. With Ames in the lead role, the Langley Research Center and Lewis Research Center support the NASA rotorcraft program in their areas of expertise. This new alignment of center roles was implemented to strengthen and expand NASA's ability to conduct a broad based research effort.

An important adjunct to the NASA organization is the joint research arrangement with the U.S. Army. Through laboratories collocated at Ames, Langley and Lewis, the Aviation Research and Development Command (AVRADCOM) conducts research in aeromechanics, structures, and propulsion. In addition, the AVRADCOM Applied Technology Laboratory is located at Fort Eustis, Virginia. The NASA manpower directly applied to rotorcraft tasks is approximately 290. The Army manpower at the three centers totals approximately 240, with many of the staff working directly with NASA groups on research of common interest.

The major National investment in NASA facilities offers an excellent opportunity for conducting rotorcraft research. In fact, many of the capabilities are unique. The 40 x 80 Foot Tunnel and the Flight Simulator for Advanced Aircraft at Ames (Figure IV-2) and the Transonic Dynamic Tunnel at Langley are examples of unique ground facilities ideally suited to rotorcraft research. Other wind tunnel and ground test facilities at Ames, Langley and Lewis are also key assets available for aerodynamic, structural and propulsion research.

In addition to the ground based research facilities, there are a number of flight research aircraft available (Figure IV-3). Two research vehicles now

being readied for delivery to Ames Research Center are the Rotor Systems Research Aircraft (RSRA) and the XV-15 Tilt Rotor Research Aircraft (TRRA). Both of these research vehicle programs are jointly funded and managed by the Army and NASA. The RSRA will be used for rotor systems research and for general flight research to develop and verify advanced analytical methods related to pure and compound helicopter configuration research. The TRRA will be used in proof-of-concept flight testing and then will be used by NASA and the Army for mission suitability investigations.

The CH-53, SH-3 and CH-47 aircraft are available for operations research including advanced systems evaluation, displays, and automatic guidance and navigation research. As usual, other aircraft of opportunity have been, and will continue to be, used to conduct research on airfoils, tip-shapes, special flight control and avionic systems, etc.

Ongoing Research

The current NASA rotorcraft program evolved from autogyro research begun in the 1930's by the National Advisory Committee for Aeronautics, NACA. Valuable contributions to autogyro and helicopter technology have resulted from the research conducted and sponsored by NACA/NASA over the years. A close association developed between NACA/NASA and the military rotorcraft R&D groups. This was particularly true of the U.S. Army with many years of both formal and informal cooperative efforts. In 1965, the first Joint Agreement with the Army provided for the establishment of an Army Aeronautical Research Laboratory at Ames and shortly thereafter NASA's funding in rotorcraft research began to increase Over the ensuing five years, NASA and the Army shared resources to pursue research activities of common interest in the areas of aerodynamics and structural dynamics of rotors. These concepts were extended in 1970 when the Army established the organization that is currently called the Research and Technology Laboratories of the U.S. Army Aviation R and D Command (AVRADCOM). At that time, NASA/Army joint agreements were initiated at the Langley and Lewis Research Centers and the Army activity at Ames was expanded. In general, the activities that have been pursued at all Centers have fallen in the category of Research and Technology Base activities. However, in 1972, NASA and the Army agreed to jointly fund the Rotor Systems Research Aircraft (RSRA) and the Tilt

Rotor Research Aircraft (TRRA) programs. These two Experimental Programs represented a major funding commitment which was spread over the mid-1970's with equal funding by the Army and NASA. Over the same time period, the other ongoing research activities continued to grow, as the close working relationship continued.

While the military's interest in the utilization of the helicopter was the primary driving force in its development through the mid-1970's, NASA recognized the commonality of civil and military interests in the fundamental problems and basic technologies. The current deficiencies that limit the utilization of helicopters are essentially the same for both civil and military operations. Dynamic loads, reliability and maintainability and life cycle costs continue to be the high priority concerns of both military and civil users. The joint research activities are basically complementary.

NASA traditionally places emphasis on providing technology in a "far term" context and does not have to wait for a hard mission requirement to be generated. The Army supplements NASA technology activity and places emphasis on the more "near term" mission oriented research and applied technology.

Rotorcraft Task Force

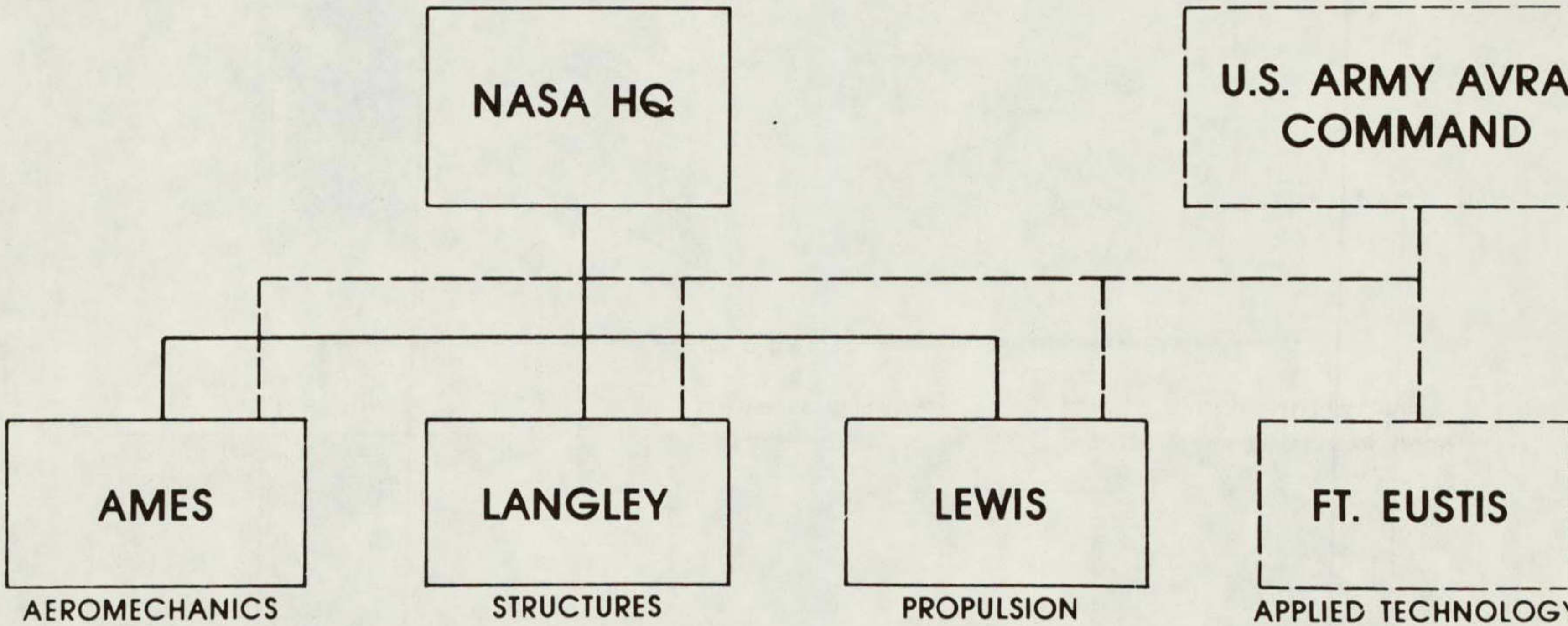
In March 1978 the Office of Aeronautics and Space Technology formed an ad hoc Rotorcraft Task Force to review rotorcraft technology needs, center capabilities, and ongoing research; and to prepare an appropriate rotorcraft research program plan based on the findings. Figure IV-4 lists the members of the Task Force. In addition to the NASA Headquarters and center representation, members included FAA, Army and Navy representatives. The Task Force schedule is shown in Figure IV-5. The initial Task Force meeting was held on March 28, 1978.

The primary activity in April and May was soliciting the rotorcraft industry and other government agencies for their positions on the state of technology and the future technology needs. Figure IV-6 lists some of the key events in this Task Force interface with the industry.

In order to assure proper outside review and critique of the program plan formulation, an ad hoc Committee on Rotorcraft Technology was created at NASA request, by the National Research Council as a subcommittee of the Aeronautics and Space Engineering Board (ASEB). The membership of the ASEB ad hoc Committee is listed in Figure IV-7. The membership includes representatives of industry, universities, civil users, Army, Navy, and FAA. Briefings were given to the ad hoc Committee on June 1 and 21, 1978, and the draft final plan was transmitted for final review and comment on July 18.

The recommended program plan which gradually evolved as a result of meetings between the Task Force and the NASA Centers, industry, users, and the ad hoc Committee is presented in the following sections.

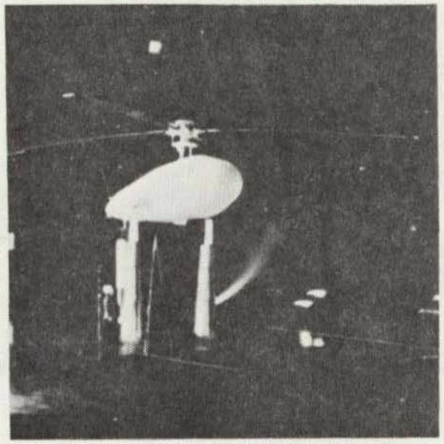
NASA ORGANIZATION OF EFFORT



- CONDUCT RESEARCH AND TECHNOLOGY DEVELOPMENT
- OPERATE UNIQUE FACILITIES

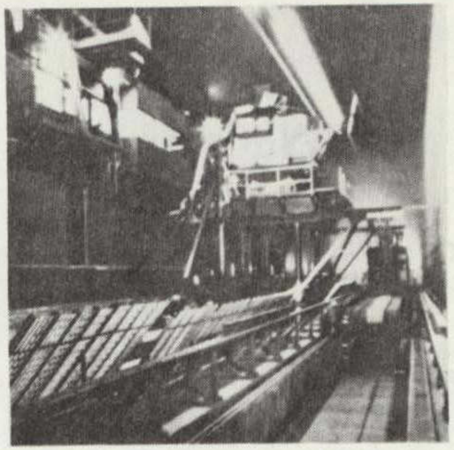
FIGURE IV-1

GROUND FACILITIES



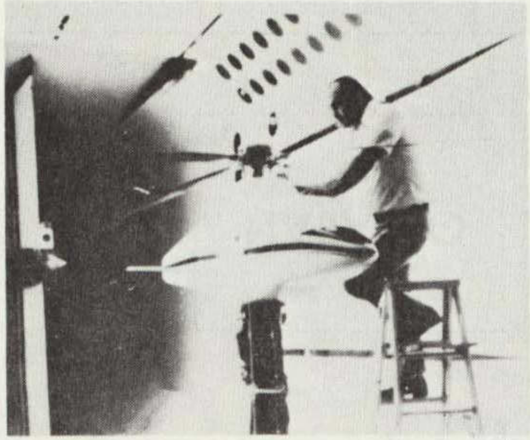
40 X 80 FT TUNNEL

11 X 11 TRANSONIC TUNNEL



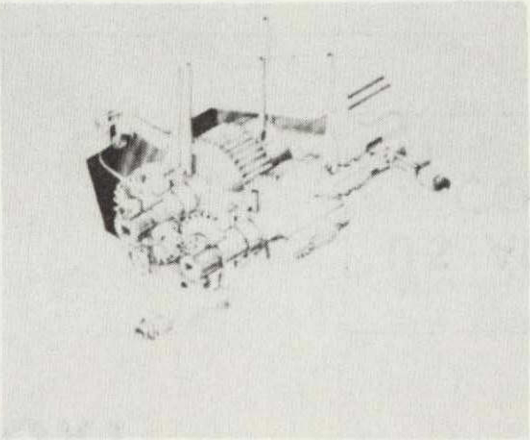
FLIGHT SIMULATORS

AMES



TRANSONIC DYNAMICS TUNNEL

LANGLEY



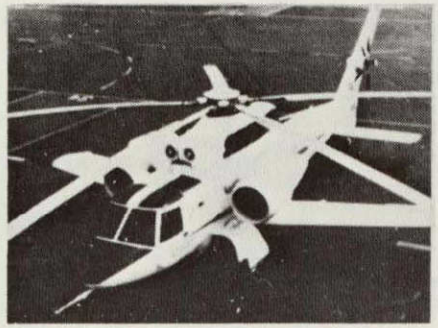
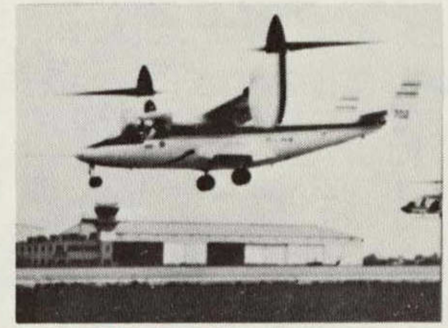
GEAR TEST RIG

LEWIS

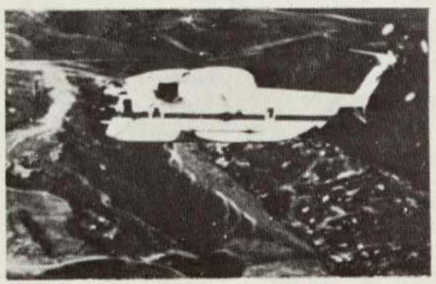
NASA HQ RX78 1994 3
4 21 78

FIGURE IV-2

RESEARCH AIRCRAFT

CONFIGURATION RESEARCH



OPERATING RESEARCH


AIRFOIL RESEARCH

NASA HQ RX78 2058(3)
4-21-78

FIGURE IV-3

ROTORCRAFT TASK FORCE

HEADQUARTERS

DR. JOHN M. KLINEBERG (CHAIRMAN)
MR. JOHN F. WARD
MR. RALPH W. MAY
DR. ANTHONY K. AMOS
MRS. PHYLLIS WILSON

CENTERS

ARC	-	MR. JOHN W. BOYD
		MR. KIPLING H. EDENBOROUGH
		MR. JAY CHRISTENSEN
LARC	-	MR. JULIAN L. JENKINS
LERC	-	MR. RICHARD A. RUDEY
DFRC	-	MR. JOHN G. MCTIGUE

ARMY - MR. DEAN C. BORGMAN

FAA - MR. MIKE NELSON (LCOL. TOM WEST)

NAVY - MR. HAROLD ANDREWS

HEADQUARTERS DIVISION COORDINATION AND SUPPORT

MR. DAVID J. MILLER	RL	-	AERONAUTICAL PROPULSION DIVISION
MR. JACK D. BREWER	RH	-	AERODYNAMICS & VEHICLE SYSTEMS DIVISION
MR. LEE D. GOOLSBY	RO	-	AERONAUTICAL OPERATING SYSTEMS DIVISION
MR. GENE E. LYMAN	RB	-	AERONAUTICAL MAN-VEHICLE TECHNOLOGY DIVISION
MR. LAWRENCE W. TAYLOR	RE	-	ELECTRONICS DIVISION
DR. MICHAEL J. SALKIND	RW	-	MATERIALS & STRUCTURES DIVISION

FIGURE IV-4

ROTORCRAFT TASK FORCE
SCHEDULE

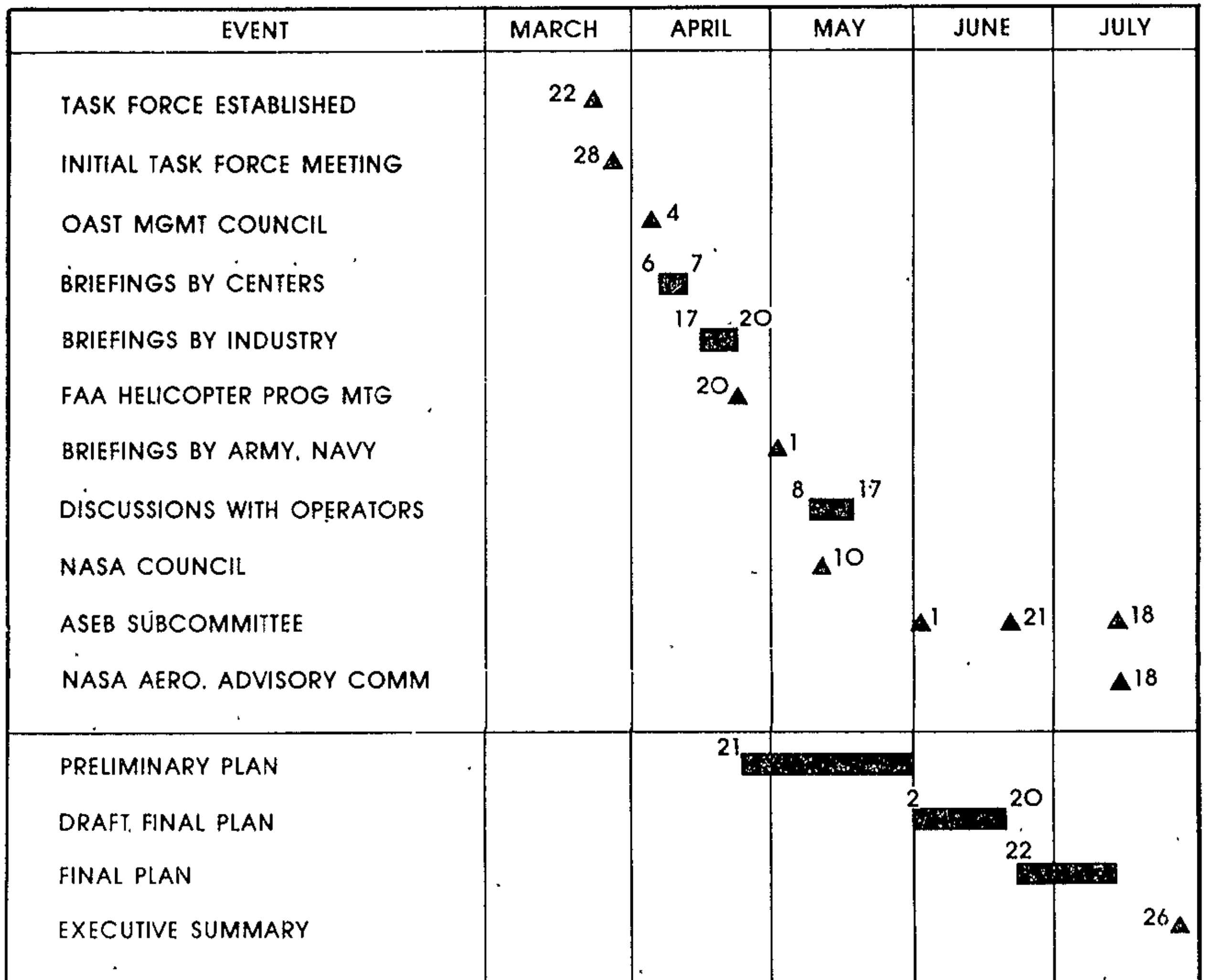


FIGURE IV-5

NRC — AERONAUTICS AND SPACE ENGINEERING BOARD

AD HOC COMMITTEE ON ROTORCRAFT TECHNOLOGY

Prof. Rene H. Miller, MIT, Chairman
Dr. B. Paul Blasingame, DELCO Electronics Div, GMC
Capt. John A. Cameron, British Airways Helicopters
Mr. Charles M. Ellis, Boeing-Vertol Company
Mr. Glen A. Gilbert, Glen Gilbert Associates
Mr. John N. Kerr, Hughes Helicopters
Mr. Robert R. Lynn, Bell Helicopter Textron
Dr. Barnes McCormick, The Penn State University
Mr. Wayne McIntire, Detroit Diesel Allison
Rear Adm. Jack F. O'Hara, Navy Department
Mr. William F. Paul, Sikorsky Aircraft
Mr. Bruce Reese, Purdue University
Mr. David Sheftel, Federal Aviation Administration
Mr. Robert Suggs, Petroleum Helicopters, Inc.
Dr. Henry R. Velkoff, Ohio State University
Dr. Joseph H. Yang, Department of the Army
Mr. Albert J. Evans, ASEB, Executive Secretary

FIGURE IV-6

ROTORCRAFT TASK FORCE
INTERFACE WITH ROTORCRAFT INDUSTRY

APRIL 17-20, 1978

AIRFRAME AND ENGINE MANUFACTURER BRIEFINGS:

BELL HELICOPTER TEXTRON
BOEING VERTOL COMPANY
HUGHES HELICOPTERS
KAMAN AEROSPACE

SIKORSKY AIRCRAFT
AVCO-LYCOMING
DETROIT DIESEL ALLISON
GARRETT AIRESEARCH
GENERAL ELECTRIC

APRIL 20, 1978

FAA HELICOPTER PROGRAM REVIEW MEETING

MAY 1, 1978

ARMY-AVIATION RESEARCH AND DEVELOPMENT COMMAND BRIEFING

MAY 15, 1978

HELICOPTER ASSOCIATION OF AMERICA

MAY 15-17, 1978

AMERICAN HELICOPTER SOCIETY NATIONAL FORUM

MAY 26, 1978

NAVAL AIR SYSTEMS COMMAND BRIEFING

FIGURE IV-7

PROGRAM PLAN

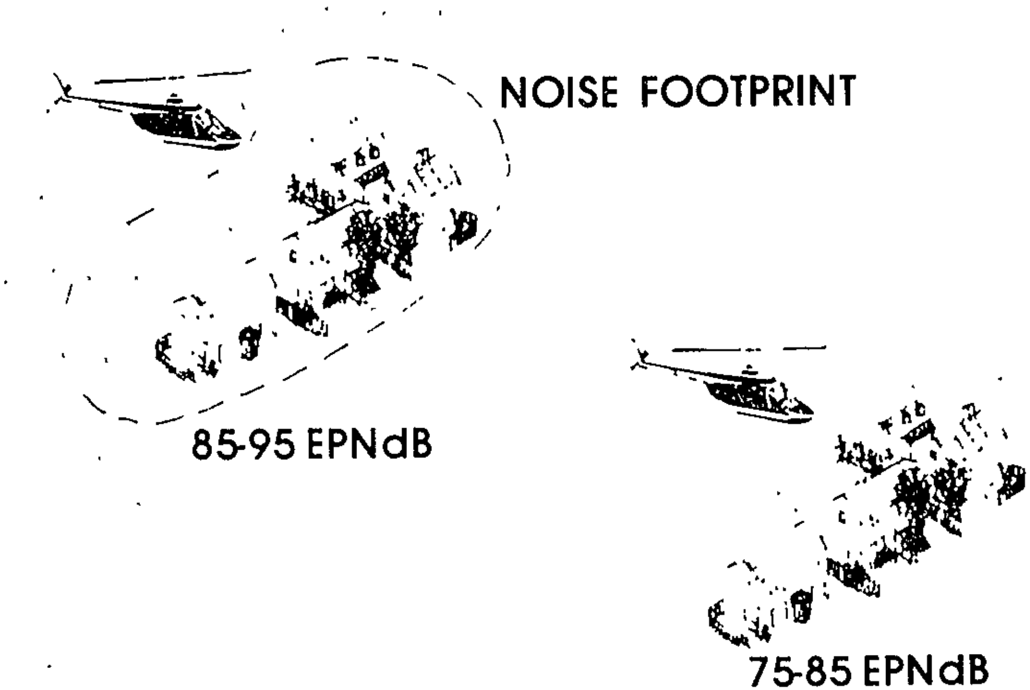
The following rotorcraft program plan presents the research tasks and an estimate of the funding required to assure that NASA applies expertise and unique capabilities to effectively respond to the Nation's needs in rotorcraft technology. The plan covers a period from Fiscal Year 1980 through 1989. It is built upon the current on-going effort to provide a balanced and integrated effort which draws from the generic programs in aerodynamics, structures, avionics, operating systems, propulsion, and human-vehicle research and technology.

The basis for the program is the future technology needs identified by the Task Force during meetings with the industry and users. These needs are listed below and are illustrated in Figures V-1 through V-8.

- Noise reduction
- Vibration reduction
- Reliability and maintainability improvement
- All-weather capability
- Safety improvements
- Flying/ride quality improvement
- Productivity improvement
- Reduced fuel consumption

The Advanced Rotorcraft Technology Program, which is presented in the following sections, is structured in the main program elements and task areas shown in Figure V-9 and Figure V-10. The new program builds on the ongoing program at the Ames, Langley, and Lewis Research Centers in generic research, and augments ongoing work in rotorcraft aerodynamics, operating systems, power transfer and flight testing. Major emphasis is placed on the use of unique NASA capabilities to develop verified analytical methods and design methodology in the areas of rotor and rotor/airframe aerodynamics, acoustics, vibration reduction, composite airframe design, all-weather capability, engine and drive system components, and advanced vehicle configurations. The implementation of this program would involve in-house and contracted research to assure close coordination with industry. Many opportunities exist for joint programs with industry and the Department of Defense. These opportunities would be continually assessed as the program implementation progressed.

NOISE REDUCTION



- IMPROVED COMMUNITY ACCEPTANCE
- REDUCED OPERATING RESTRICTIONS
- INCREASED PRODUCTIVITY

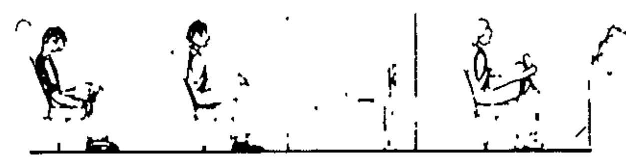
GOAL

85 EPNdB NOISE FOOTPRINT CONTAINED WITHIN HELIPORT BOUNDARIES.

FIGURE V-1

VIBRATION REDUCTION

0.1-0.3g



0.01-0.05g

- REDUCED MAINTENANCE
- IMPROVED PASSENGER ACCEPTANCE
- INCREASED RELIABILITY

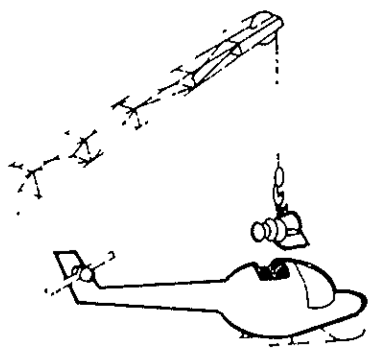
GOAL

VIBRATION LEVELS FOR PASSENGERS/
CREW/EQUIPMENT EQUIVALENT TO
JUMBO JET FIXED WING AIRCRAFT.

FIGURE V-2

RELIABILITY AND MAINTAINABILITY

MAJOR SYSTEMS
MTBR = N HOURS



MAJOR SYSTEMS
MTBR = 3N HOURS/
ON-CONDITION

- LOWER OPERATING COSTS
- INCREASED AVAILABILITY
- IMPROVED SAFETY

GOAL

IMPROVE RELIABILITY AND
MAINTAINABILITY BY A FACTOR OF 3.

FIGURE V-3

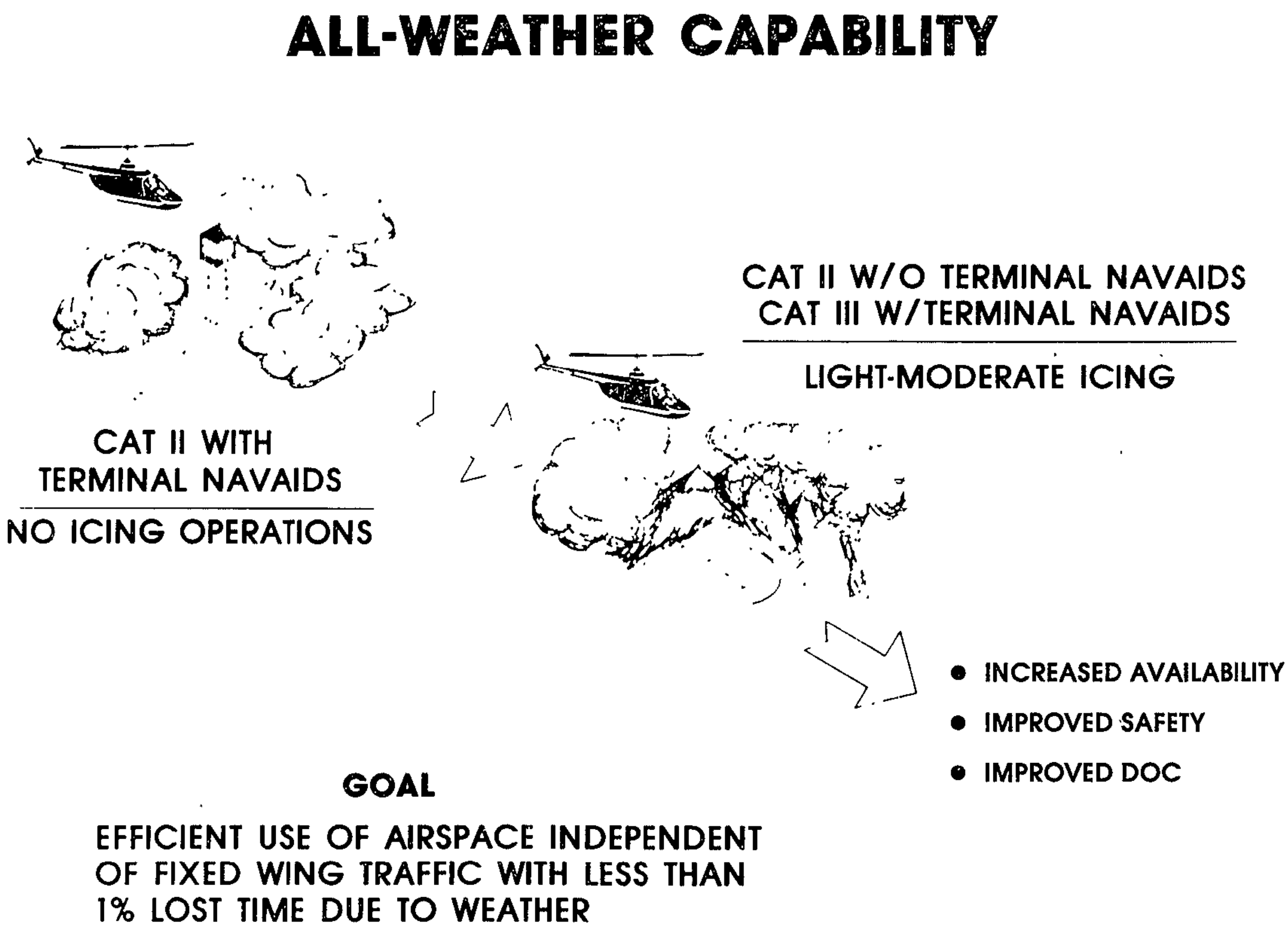
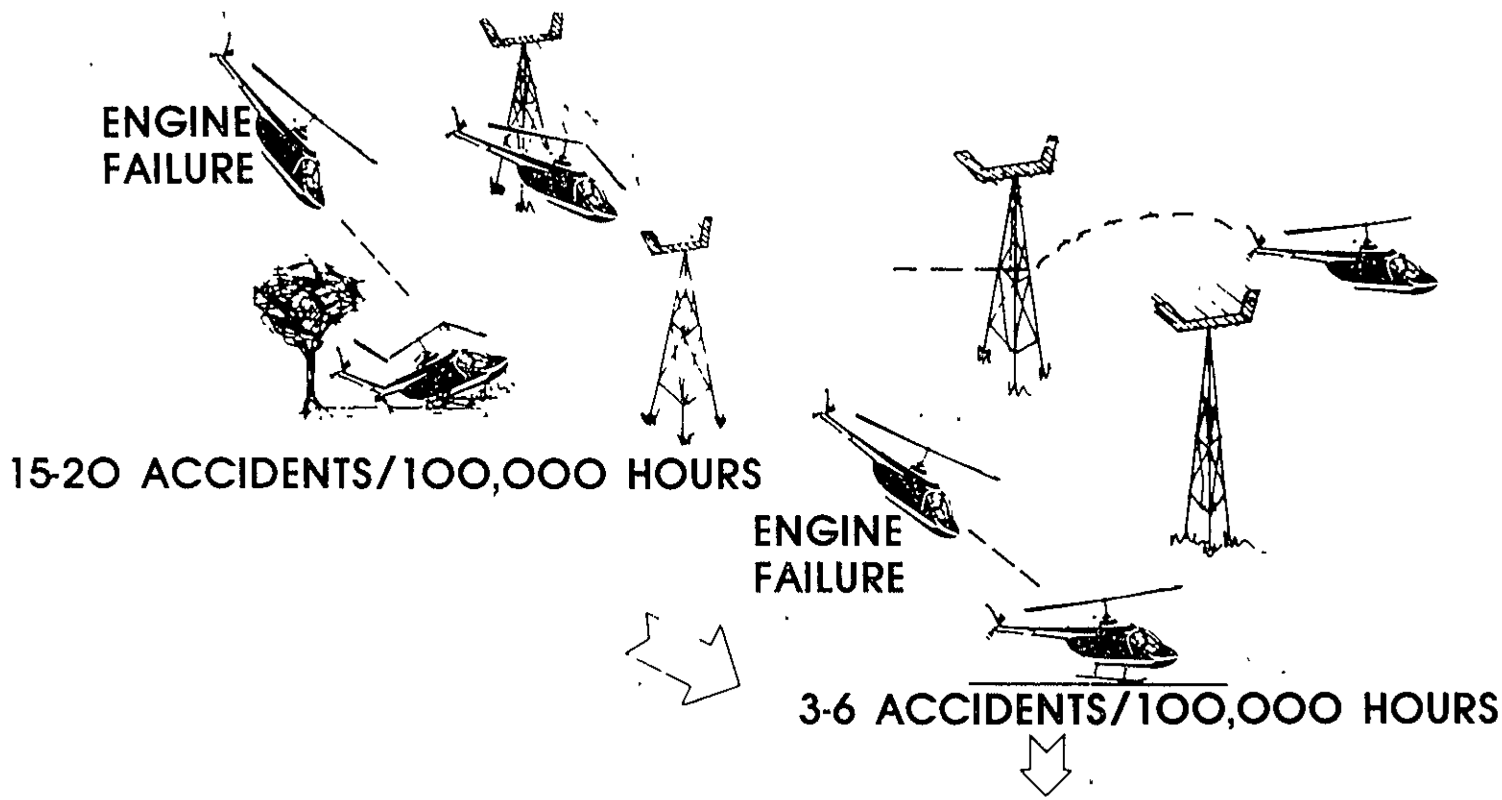

ALL-WEATHER CAPABILITY
CAT II WITH TERMINAL NAVAIDS
NO ICING OPERATIONS
CAT II W/O TERMINAL NAVAIDS
CAT III W/TERMINAL NAVAIDS
LIGHT-MODERATE ICING
• INCREASED AVAILABILITY
• IMPROVED SAFETY
• IMPROVED DOC
GOAL
EFFICIENT USE OF AIRSPACE INDEPENDENT OF FIXED WING TRAFFIC WITH LESS THAN 1% LOST TIME DUE TO WEATHER

FIGURE V-4

SAFETY IMPROVEMENT



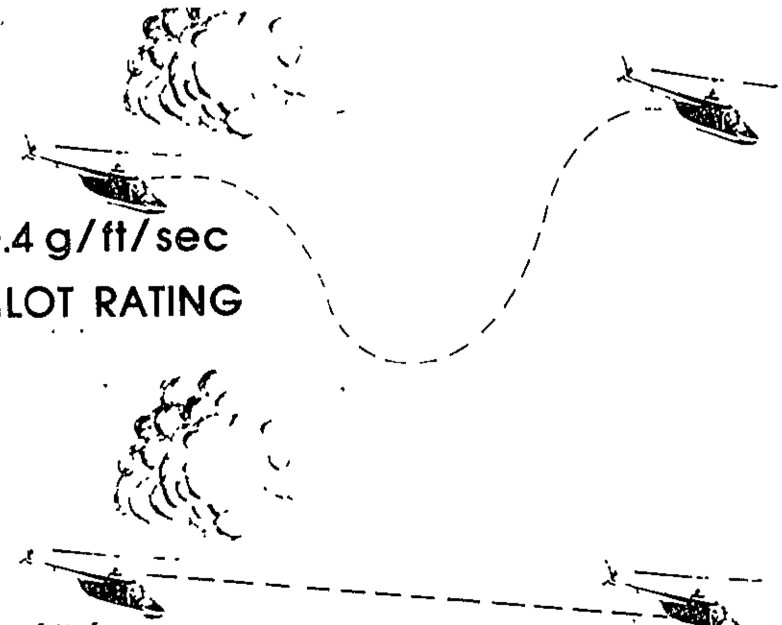
GOAL

- 5-FOLD REDUCTION IN THE ACCIDENT RATE

- INCREASED ACCEPTANCE
- REDUCED INSURANCE RATES
- REDUCED COSTS

FIGURE V-5

FLYING/RIDE QUALITY IMPROVEMENT



- IMPROVED SAFETY
- INCREASED PILOT ACCEPTANCE
- INCREASED PASSENGER ACCEPTANCE

GOAL

NO SIGNIFICANT DIFFERENCE IN FLYING/RIDE QUALITY AS PASSENGER TRANSFERS FROM "JET SMOOTH" FIXED WING TO ROTORCRAFT.

FIGURE V-6

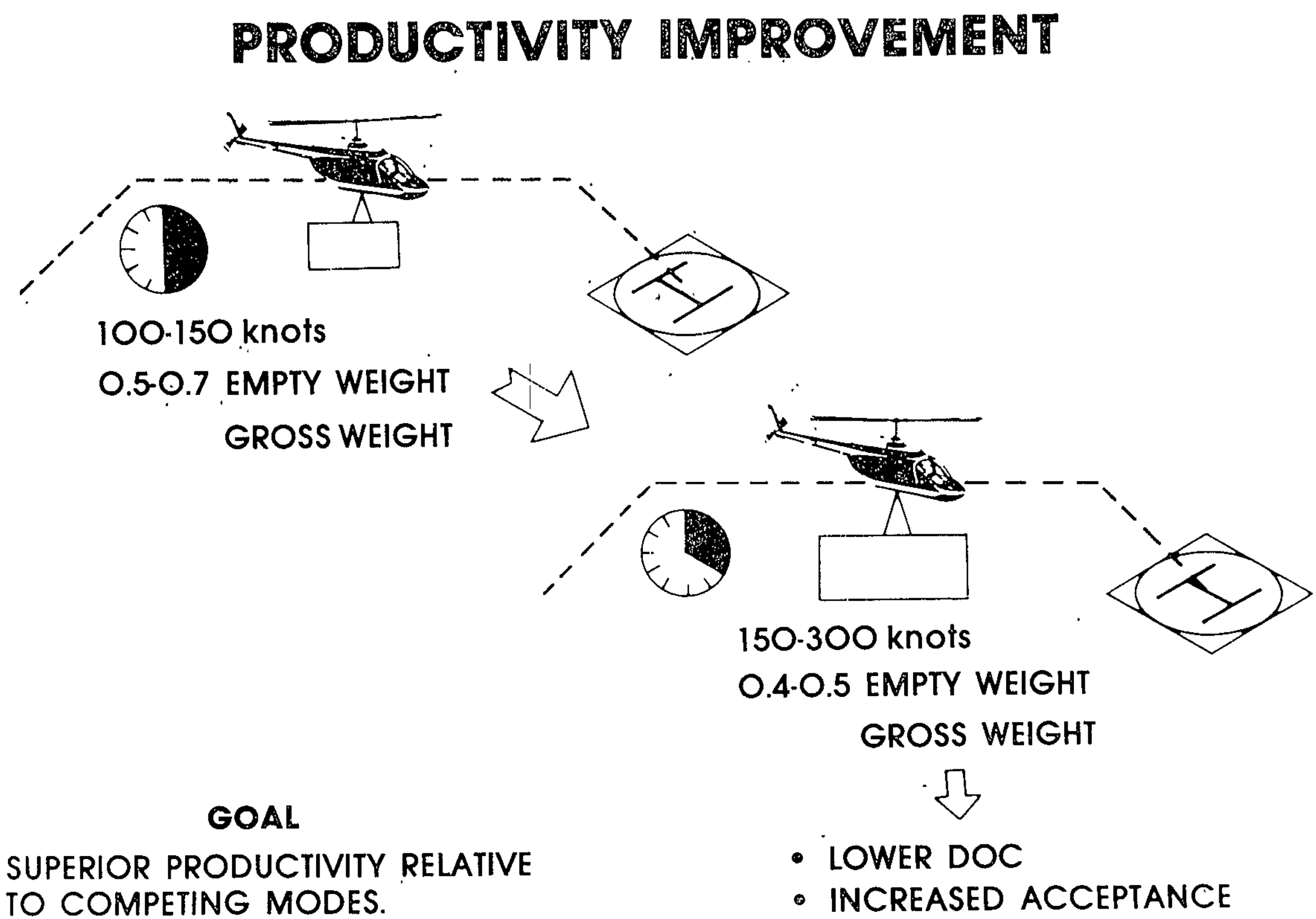
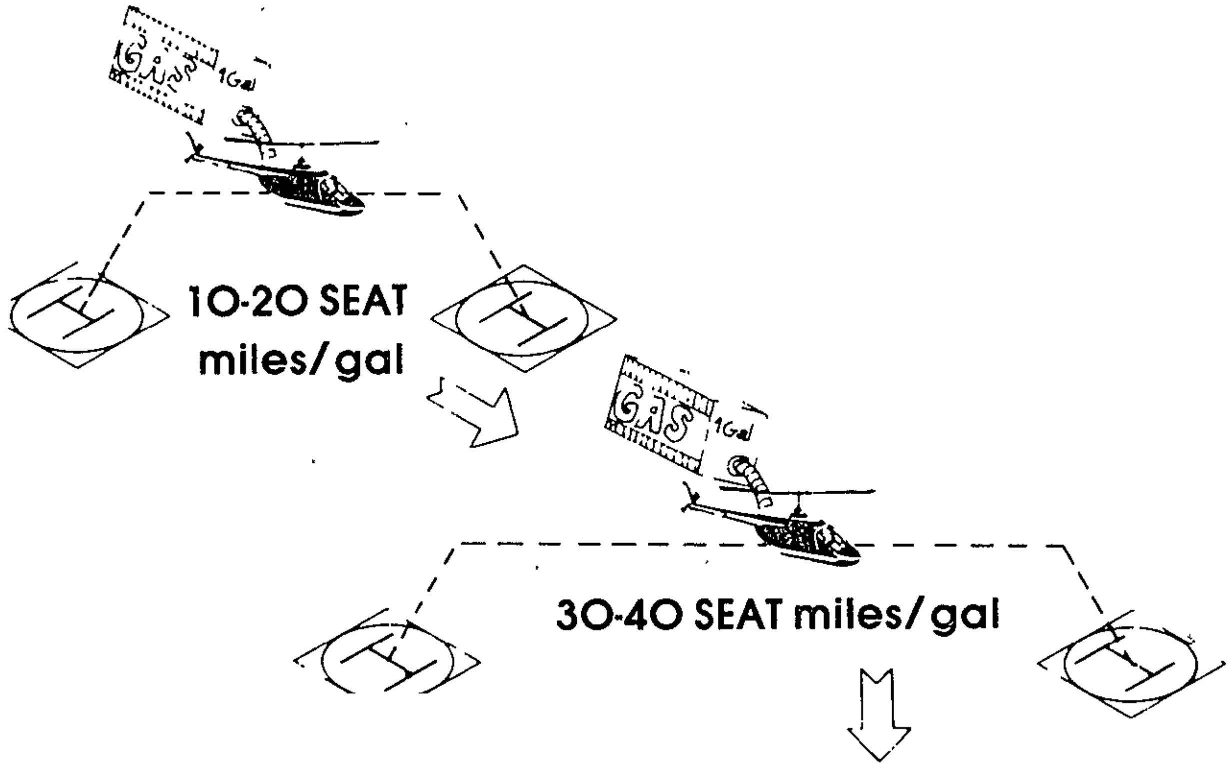

PRODUCTIVITY IMPROVEMENT
100-150 knots
0.5-0.7 EMPTY WEIGHT
GROSS WEIGHT
150-300 knots
0.4-0.5 EMPTY WEIGHT
GROSS WEIGHT
GOAL
SUPERIOR PRODUCTIVITY RELATIVE TO COMPETING MODES.
• LOWER DOC
• INCREASED ACCEPTANCE

FIGURE V-7

FUEL CONSUMPTION IMPROVEMENT



GOAL

LONG TERM FLEET FUEL SAVINGS
OF 20 PERCENT OR APPROXIMATELY
$60M/YEAR

- LOWER DOC
- INCREASED RANGE
- INCREASED ENDURANCE

FIGURE V-8

ADVANCED ROTORCRAFT TECHNOLOGY

PROGRAM ELEMENTS

AERODYNAMICS AND STRUCTURES

AERODYNAMICS/ACOUSTICS
VIBRATION REDUCTION
COMPOSITE AIRFRAME

PROPULSION

ENGINE COMPONENT DESIGN METHODOLOGY
POWER TRANSFER TECHNOLOGY
SYSTEMS INTEGRATION

FLIGHT CONTROL AND AVIONIC SYSTEMS

ALL-WEATHER
ACTIVE CONTROL

VEHICLE CONFIGURATIONS

HIGH SPEED CONCEPTS
LARGE ROTORCRAFT CONCEPTS

FIGURE V-9

ADVANCED ROTORCRAFT TECHNOLOGY
PROGRAM ELEMENTS

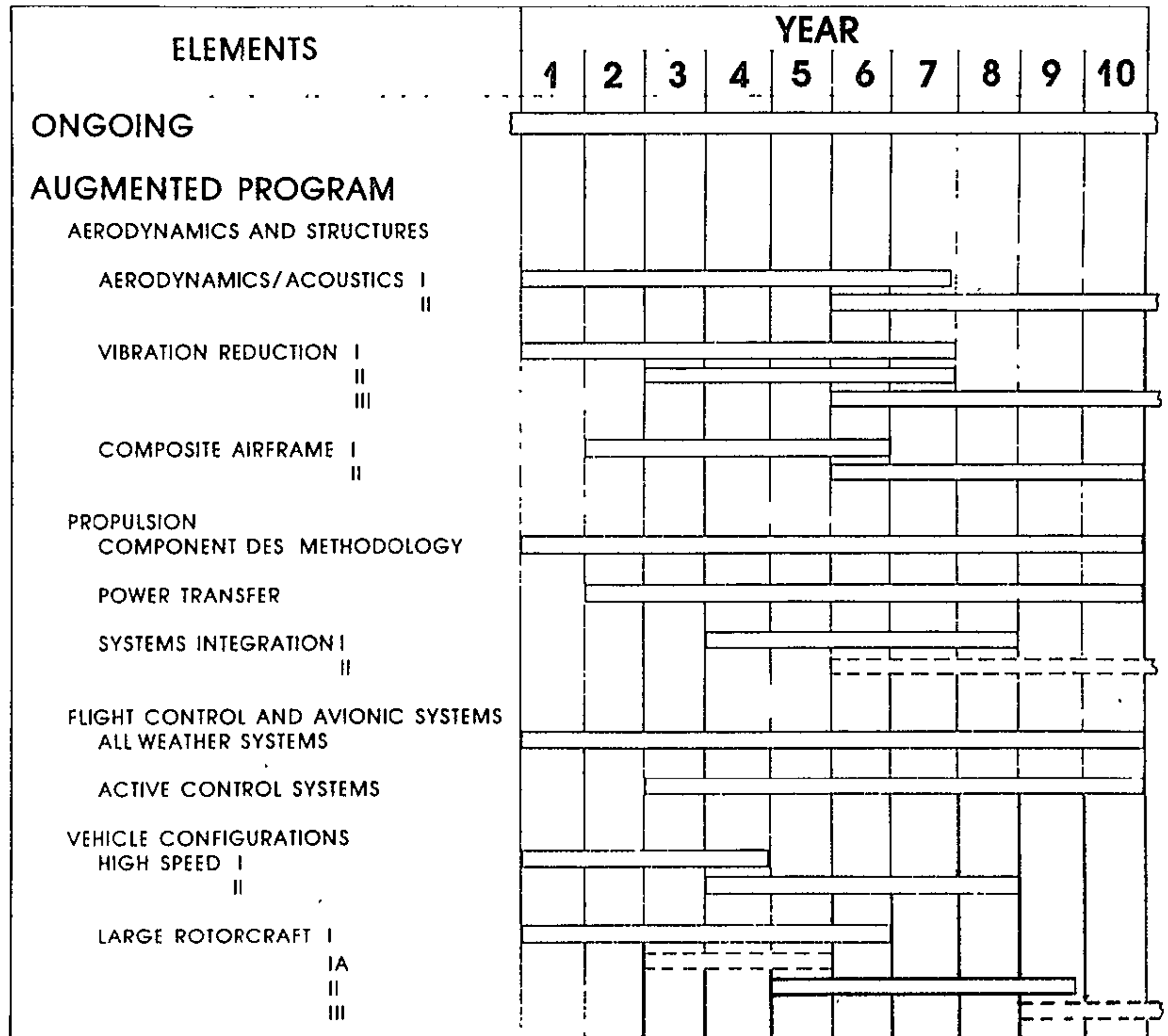


FIGURE V-10

AERODYNAMICS AND STRUCTURES

The Task Force considered a wide range of rotorcraft technology needs in the broad disciplinary areas of aerodynamics, structural dynamics, acoustics and advanced materials applications--both separately as well as in interdisciplinary fashion as can appropriately be addressed in research on total systems such as advanced rotor systems. Based on strong recommendation from the Ad Hoc Committee on Rotorcraft Technology of the Aeronautics and Space Engineering Board of the National Research Council, the Task Force concentrated on defining programs to improve and develop design methodology in key areas which cannot be adequately covered within ongoing research under aeromechanics and rotor systems. Three Aerodynamics and Structures design methodology programs were identified as listed in Figure VI-1.

The Aero/Acoustics program is aimed at producing design methods to predict and improve helicopter efficiency, utility and aerodynamic source noise. The first program phase provides for systematic small and large-scale tests of a rotor family and complete helicopter configuration with heavy emphasis on detailed flow, acoustic and aerodynamic parameter measurements and the development of improved analytical prediction methods as a strong basis for developing the design methodology. The second and later phase involves use of the design methodology to design and predict characteristics of specific second generation rotors, followed by testing to check out the predictions and to update the methods as may be required.

The Vibration program in the first phase concentrates on airframe loads and structural modeling design methodology. Helicopter vibration is a major factor impacting maintenance costs, safety and ride quality. Current prediction methods are inadequate in many respects and not well understood. An industry/government team approach will be utilized to assist in generating more widely acceptable and useable prediction and modeling methods. Program elements related to the vibration prediction methodology include in-service flight load measurements during civil helicopter operation, use of active controls to suppress vibration, and internal noise. Later phases of the Vibration program address design methodology for potentially large improvements through use of advanced materials and structural concepts in the hub and rotor areas.

The third program emphasizing design methodology is the Composite Airframe program. The use of composite materials for rotor blades is accelerating to increase utility and decrease lifetime costs, and for airframe secondary structural elements to reduce cost and weight. The largest potential for helicopter weight and acquisition cost reduction, however, remains the use of composites for the integrated fuselage primary structure. The first phase of the Composite Airframe program embodies composite fuselage design studies including associated experimental assessment of critical areas. The second phase consists of build-up and thorough ground-based testing of a major fuselage component.

The three Aerodynamics and Structures programs developed by the Task Force are described in greater detail in the following sections.

AERO/ACOUSTICS

PURPOSE: Provide validated design prediction methods and a data base to sustain the development of vehicles which can attain future stringent noise and performance standards (Figure VI-2).

BENEFITS: Provide the design tools, methodology and substantiating aero/acoustics data base for improved helicopter designs having

- External noise reduction of 5-10 dB
- Hover efficiency improvement of 10%
- Cruise efficiency improvement of 20%.

The design methodology will include analytical prediction methods, a comprehensive data base on rotor parameters affecting performance, noise, and established criteria for structuring small-scale aero/acoustics model tests as well as the accurate projection of results to full-scale design.

JUSTIFICATION: Despite the continued strong growth in helicopter civil usage, limitations in payload, range and forward speed frequently pose serious economic and utility shortcomings for the operator. Improvements in both hover and cruise efficiency are possible and clearly called for. In some flight regimes and design configurations, undesirable flows occur with adverse implications concerning safety and good flying qualities. The increased civil helicopter usage is also bringing demands for dramatically reduced external noise to the community and general public. Stricter noise ordinances are on the horizon which would seriously limit the operation of current helicopters, and which will present severe technical challenges as to feasibility of compliance in future economically viable helicopter designs.

There is a strong and often direct relationship or tradeoff between aerodynamic efficiency and aerodynamic source noise, especially that from main and tail rotors. A fundamental requirement for progress on helicopter aero/acoustics is a much better detailed understanding and ability to predict helicopter rotor and vechicle configuration flows than currently exists. The Task Force in its interactions with industry encountered universal and persistently strong requests for design methodology enabling improved ability to predict the detailed flows around both isolated rotors and rotor/airframe configurations with the many flow interactions of the vehicle components and the ground. The requests included the need for a large body of systematic data on flow measurements and the associated aerodynamic performance and acoustics for both isolated rotors and complete helicopter configurations as a basis for building the design methodology. The prime initial requirement is for design methodology rather than tests conducted to promote specific improved designs. One exception is for tests of some promising approaches to reduce rotor noise, because the pressure for noise reduction will likely require some major near term solutions before satisfactory predictive capability can be achieved.

Although the design methodology goal is for the most accurate and usable analytical tools that can be achieved for aero/acoustic design predictions, the realistic projections of the helicopter community are that wind-tunnel testing of sub-scale models will likely always remain a vital step in the helicopter design and development process. Accordingly, urgent requirements exist to improve the methodology for structuring small-scale wind-tunnel model design and test techniques, as well as the confident

projection of the test results to full-scale design in the flight environment.

PROGRAM: The Aero/Acoustics program defined by the Task Force consists of two phases as shown in Figure VI-3. The first phase concentrates on developing and validating aero/acoustic design methodology. It incorporates extensive small- and large-scale wind-tunnel aero/acoustic tests of both a family of related isolated rotors as well as a complete helicopter configuration incorporating one of the family rotors. The aero/acoustics characteristics of the complete helicopter configuration will also be thoroughly documented in flight as a vital link in the total body of systematic data geared almost totally to support the prediction analyses of design prediction methods which are the end objective of the first program phase.

In the second and later phase, the methodology from the first phase will be used to predict the aero/acoustic characteristics of second generation rotor designs, followed by ground and flight test to verify and further refine the design methods.

PHASE I - DESIGN METHODOLOGY DEVELOPMENT/VALIDATION

1. Isolated Rotor Aero/Acoustics - Figure IV-4 depicts some of the complex flows of a main rotor in cruise flight. Tip areas of the advancing blade on the right experience compressible flow with transonic shocks. A lifting rotor blade sheds a downward sheet of vortices as a wake, and also a strong tip vortex which impulsively interacts with the following blade. Radial flow is encountered on blades when aligned to the incoming flight airflow. The retreating blade at higher speeds encounters reverse velocity on the inner sections, and flow separation on the outer sections at the high blade angles required to generate lift. Of course, the rotor blade is highly responsive to many of the aerodynamic inputs, so aeroelasticity must be taken into first order account. Accordingly, it is understandable that existing rotor prediction methods are far short of the needs for rigorous and detailed aero/acoustic design purposes. This is especially true for new rotor designs with nonlinear planform, twist and airfoil variations.

Figure VI-5 illustrates graphically the combined experimental and analytical approach to be taken in attacking the problem to provide validated design prediction methods for the complex rotor flows. The upper right photo shows laser velocimeter flow measurements near a small-scale rotor. The other photo shows a full-scale rotor in the Ames 40- x 80-foot tunnel with microphones in place for acoustic measurments. Of course, the rotor family to be investigated at both small- and large-scale will undergo complete flow, pressure, acoustic, loads and performance measurements.

The rotor family depicted in Figure VI-6 will probably consist of three related rotors having a common fixed airfoil type, chord, diameter and four-blade configuration. Preliminary design studies will be conducted at the outset

to help establish details of the desired variables in the family. Special consideration will be given to provide data for design features which may alleviate noise. In this connection, it is planned that several interchangeable blade tips will be evaluated on each of the rotors.

Figure VI-7 is included in the program plan to emphasize again that each rotor in the family will be tested at both small and large scale together with concentrated analysis of scale modeling to provide a substantive data base on scale effects and validated methods for scale modeling.

Figure VI-8 conveys how data from the rotor family tests will be combined with results from several more fundamental analytical and experimental investigations involving computer graphic techniques, rotor wake computation, unsteady aerodynamics of rapidly pitching and plunging airfoils in rotor blades, and rotor tip vortex interactions--all focused and coordinated toward producing comprehensive rotor flow modeling and prediction methods.

The sketch at the upper right of Figure VI-9 depicts three primary rotor aerodynamic noise sources which will be investigated, not only as to their intensity, but also as to their directivity and propagation. Apart from the extensive acoustic measurements to be taken during each of the small- and large-scale rotor tests, focused efforts will be undertaken on rotor acoustic theories and experimental modeling data as illustrated by the rotor in an acoustic chamber in the lower left of Figure VI-9. The comprehensive rotor source noise analysis will include concentrated efforts through the expertise and facilities of the Langley Research Center Aircraft Noise Reduction

Laboratory. In addition, NASA and Army cooperative research efforts will be continued and augmented using the acoustic chamber and the YO-3A aircraft at Ames Research Center.

2. Rotor/Airframe Interactions - When main or tail rotors are integrated into a helicopter configuration, additional flow interactions come into play having important effects on total vehicle aero/acoustics as partially illustrated in Figure VI-10. The airframe can influence flow into the main rotor(s) and especially into and from a tail rotor. Rotor-rotor interactions can be extremely important and difficult to predict for some critical flight regimes. The aerodynamics of the airframe are heavily influenced by varying flow from the rotors. The flow interactions and influence on drag are very large in the region of the hub, pylon and propulsion system inlets and nozzles. Aero/acoustic prediction methods are seriously inadequate for the design of future helicopters to meet more stringent noise and performance standards.

Figure VI-11 and VI-12 illustrate the program to be undertaken in obtaining an experimental and analytic understanding and design prediction capability for the vehicle flow aero/acoustic interactions. Preliminary design studies and early results from the isolated rotor family efforts will provide guidance in selecting one rotor of the family to investigate thoroughly on an existing sub-scale model of RSRA, on a full-sized experimental model of RSRA to be provided for test in the 40- x 80- and 80- x 120-foot tunnels, and in flight on RSRA itself. The RSRA will be used as the baseline configuration, inasmuch as it provides a far greater flight envelope test capability with special instrumentation than available on a production helicopter.

Together with the comprehensive wind tunnel and flight tests, major parallel and iterative efforts will be undertaken to extend the isolated rotor prediction methods to incorporate vehicle interaction effects. The end product of the Phase I Aero/acoustics program will be documented total configuration design methodology which hopefully is widely accepted and readily usable by the helicopter community to improve future designs.

PHASE II - SECOND GENERATION ROTOR AERO/ACOUSTICS PREDICTION AND VALIDATION

The second phase of the program will utilize results from the first phase as a guide for preliminary design and detailed prediction of the aero/acoustic characteristics of two second generation rotors as illustrated in Figure VI-13. It is premature to specify what the rotor concepts will be, but some candidate concepts are listed from today's perspective. They will likely incorporate promising features for which the design methodology from the first program phase may leave some question in regard to design capability. Both rotors will be subjected to small- and large-scale tunnel tests of a more restricted scope than under the first phase, as a basis to check and refine the prediction methods. Finally, one of the rotors will undergo flight test as a further basis for validating and updating the design prediction methodology for promising emerging rotor concepts.

AERO/ACOUSTIC PROGRAM SUMMARY

The planned time phasing of the key task elements described in the foregoing sections is summarized in Figure VI-14.

VIBRATION REDUCTION

PURPOSE: Provide focused technology and design methodology for accurate prediction and substantial reduction of airframe vibration and internal noise (see Figure VI-15).

Extend hub/rotor technology for major reduction of complexity, cost, vibration, maintenance and weight.

BENEFITS:

- Improved vibration and internal noise prediction methods which are readily available and used by the helicopter design community
- Cabin/cockpit vibration and noise approaching the comfort levels of fixed-wing transports.
- Technology for dramatically improved next generation hub/rotor concepts with goals of approximately two-thirds fewer parts than comparable U.S. articles currently in service, 10 to 50 percent less cost, jet smooth ride qualities in the cabin/cockpit, infinite life or on-condition replacement, and 10 to 50 percent less weight.

JUSTIFICATION: Vibration has been a chronic problem for helicopters. Apart from its impact on the comfort and fatigue of the crew and passengers, it also creates a heavy toll in maintenance costs and downtime, since vibratory loads often dictate component lifetime allowable before replacement, or lead to component and system failures throughout the helicopter. The helicopter is sometimes referred to as a "flying fatigue machine." Unfortunately, some vibration-induced failures may not be remedied in time to avoid flight safety hazards. Likewise, noise from concentrated sources such as the transmission, rotor system and propulsion system can be either structure-borne or air-borne inside the helicopter to become especially annoying, or even lead to hearing loss, for the crew and passengers. Accordingly, vibration and internal noise are serious deterrents to the full potential acceptance and economic utilization of helicopters in the civil sector.

Vibration is very complex in a helicopter with its large rotor systems and other rotating elements interacting dynamically with the airframe. Both industry and the government have invested heavily in structural modeling and dynamic computational methods and systems with only modest success. There are frequent complaints that the sophisticated NASTRAN finite element analysis system has not predicted helicopter structural dynamics satisfactorily over the full frequency spectrum, and that it requires an inordinate amount of time and, therefore, cost to use. Improved structural modeling computational capability, and improved statistical understanding of structural loads and environmental factors being encountered by civil helicopters are essential first steps to major progress in reduction of vibration and internal noise. These improvements must be coupled with the better understanding and prediction of rotor vibratory loads, which is addressed in the Aero/Acoustic portion of this program. Industry has had some success with rotor vibration isolation systems for some helicopters and operation conditions. Such systems tend to be unique to specific rotor and helicopter designs, and industry response to the Task Force did not indicate this to be a fruitful area for concentrated NASA research. On the other hand, the industry consensus suggested rather strongly that NASA should advance the technology for utilizing active rotor control capable of operating at the higher harmonics to alleviate rotor input vibratory loads at the source.

New materials applications and design concepts for advanced hubs and rotors have potential for not only reducing vibration, but also for improving overall cost, maintenance weight, and performance. However, because of the sensitivity of vehicle vibration to the detailed aeroelastic configuration of the rotor hub, a great deal of careful

design analysis together with technology associated with fabrication and test evaluation is required to allow the development certification of future designs with minimum risk.

PROGRAM: The first phase of the Vibration program defined by the Task Force (Figure VI-16) concerns airframe loads and modeling design methodology including technology to establish design criteria for suppressing vibration by active controls and for suppressing internal noise. The second phase covers preliminary design analysis, fabrication, and extensive ground-based experimental evaluation of advanced hub/rotor concepts to establish design criteria and methodology. The third phase provides for flight validation of the technology incorporated in one of the advanced concepts as a guide for further updating the design methodology.

PHASE I AIRFRAME LOADS & MODELING DESIGN METHODOLOGY

1. In-Service Flight Load & Environment Modeling - As illustrated in Figure VI-17, sensing, measuring and recording equipment will be installed on a number of helicopters in civil operations to record structural load, flight envelope, atmospheric and other environmental data. The instrumentation will be specially designed and configured to be as self-contained and nonobtrusive as possible for cooperating civil operators. However, more data is required than can be provided by simple VGH recorders to obtain a satisfactory data bank of structural loads and environmental factors for statistical analysis to aid in establishment of civil design criteria. For example, the equipment may include strain gages with exceedances, accelerometers, gyros, altitude, air speed, temperature, humidity, pollutant, and corrosive environment sensors. This activity will extend over a number of years, and hopefully will involve a representative variety of civil operations (i.e., off-shore transport, corporate use, slung loads, agricultural spraying, etc.). The civil design criteria to be generated should help clarify major differences

between military and civil load environemnts, and contribute to reduced maintenance and ehnanced safety in future civil operations.

2. Airframe Modeling/Test Assessment - The difficulty the helicopter industry has had in predicting airframe structural frequencies and vibratory response with finite element approaches may be due to shortcomings in the finite element methods, to inaccurate or inadequate analytical models, or to imprecise shake test data. This program task area (Figure VI-18) will involve NASA/industry participation in a workshop environment to assess and document industry design procedures, difficulties with software, modeling techniques, and shake test procedures. Airframe modeling and finite element analysis of at least two current vehicles will be performed at Langley, and correlation shake tests will be performed either at a contractor location or by the NASA/industry team at Langley. This effort will contribute detailed knowledge on how to represent mass distributions, connections, and damping coefficients in structural analysis, as well as on isolating specific areas in the analysis which need improvement.

3. Vibration/Load Module Development/Validation - In order to assure capability for accurately predicting low to moderately high frequency response, NASA will develop validated software modules for dynamic response (Figure VI-19) which are compatible with existing or evolving software systems for analysis of helicopter performance, stability, aerodynamics, and aeorelastic behavior such as the Second Generation Comprehensive Helicopter Analysis System (SGCHAS) or Integrated Program for Aerospace Vehicle Design (IPAD). The software modules will be designed for responsive and timely solution of engineering problems by minimizing input data preparation and checkout procedures. The modules will be capable of handling anisotropic materials (Composites) and, where possible, finite element methods will be extended to

automate optimization methods for resizing fuselage members with respect to weight or vibratory response. The modules will be validated through systematic correlation with detailed subassembly and fuselage tests.

4. Vibration Suppression with Active Controls - This concept utilizes small vibratory control motions to generate rotor forces to oppose the natural forcing function produced by the rotor. The use of digital technology allows the possibility of control inputs to null vibrations. The potential for vibration reduction by higher harmonic control is great, as large reductions are possible with little weight penalty. Tunnel tests have already proven the concept, but a satisfactory closed loop logic and controller technology to achieve the desired reduction over a wide range of steady intransient flight conditions has not been established. The work to be done under this program (Figure VI-20) includes conceptual design studies of systems incorporating automatic control of vibratory input/output into the collective and cyclic controls at n/rev. Simulations of the control system designs will be evaluated in both small-scale and full-scale tunnel dynamic model tests with the ultimate goal to validate design methodology for closed loop vibration suppression active controls.

5. Internal Noise Suppression - Efforts to improve noise prediction methods will range from basic studies of the physics of noise radiation and its interface with representative surfaces, to design and experimentation of systems for absorbing and dissipating acoustic energy (see Figure VI-21). The acoustic analysis of both air-borne and structure-borne noise will include experimental modeling data. Representative noise suppression and isolation systems will be evaluated by design analysis and laboratory tests. The work of the Lewis Research Center in reducing the transmission source noise will be utilized by Langley Research Center acoustic specialists in extending the technology to design light-weight systems for quiet cockpits and cabins.

PHASE II - ADVANCED HUB/ROTOR DESIGN METHODOLOGY

Innovative use of lightweight composite titanium and other advanced materials offers the potential for reduced vibration, reduced production and maintenance costs, relative simplicity through fewer parts, ease of maintenance and repairability and decreased drag by streamlining the hub/rotor system profile. Advanced design concepts will likely include techniques for passive or active vibration reduction. In this second phase program, (Figure VI-22) two or more design studies will be performed toward accomplishing these goals. The approach will not be to promote a specific all-composite hub/rotor system, but rather to examine in depth the practical use of composites and other advanced materials for realistic complete system designs having broad potential benefits. One design will be selected for large-scale fabrication and ground tests. The tests will include bench tests, static strength tests, and wind-tunnel tests in the 40- by 80-Foot Wind Tunnel. The design procedures will then be evaluated and refined.

PHASE III - FLIGHT VALIDATION OF ADVANCED HUB/ROTOR

Using the design criteria and ground test data from Phase II as a basis, a refined hub/rotor system will be designed and fabricated for flight validation in Phase III (Figure VI-23). It is anticipated that the hub/rotor system will be investigated on the RSRA. An extensive flight data bank will be obtained and used for refining the criteria which went into the hub/rotor design to produce well-documented design methodology for practical use in future rotor system developments.

VIBRATION PROGRAM SUMMARY AND FUNDING

The planned time phasing of the key task areas described in the foregoing sections is summarized in Figure VI-24.

COMPOSITE AIRFRAME

PURPOSE: Provide design methodology backed by substantiating experimental data to support extensive use of advanced composite materials in helicopter airframe structures to achieve reduced weight, reduced parts count, and simpler fabrication procedures (See Figure VI-25).

BENEFITS: Key benefits include:

Reduced acquisition costs largely through reduced parts count and simpler fabrication methods

Improved payload capability through reduced structural weight

Opportunity for design innovations to enhance crashworthiness, damage tolerance and fatigue life

JUSTIFICATION: The helicopter industry already is aggressively seeking to reap some of the benefits accruable from use of composite rotor blade construction. The industry and government likewise have current programs to evaluate the design application problems and benefits of using composite materials in secondary airframe elements. As already discussed under the Vibration program, NASA plans to work with industry in furthering the design methodology for incorporation of composites and other advanced materials in rotor hubs coupled with high technology blades. The remaining major potential use of composites is in the integrated fuselage structure including the primary structure. The potential benefits are extremely attractive, as already indicated. In addition, there is a considerable technical base in composites available within NASA and the Army Research and Technology Laboratories. The Army has supported a great deal of work in this area over the years, including the flight testing of a complete tail boom.

The technology base to support extensive application of composites in helicopter airframe structures is deficient in a number of important areas such as:

Basic material strength and durability characterization

Design criteria and procedures

Interrelationships among fabrication procedures, design methods, and mechanical properties of finished products

Although these are being addressed broadly in NASA R&T Base programs as well as in the ACEE project, there are problems and issues specific to helicopters that require special investigations.

Optimized utilization of composites in airframe structures requires a much better definitized understanding than exists today of key structural loads and flight envelope conditions being experienced during civil helicopter operations. The in-service flight loads and flight envelope data to be obtained under the vibration program will be analyzed thoroughly from the perspective of first order impact on composite material applications in fuselage design.

Beyond spin-offs from the aforementioned programs, however, a gradual build-up of key program elements is required to address design methodology unique to helicopters as described in the subsequent section.

PROGRAM: The Composite Airframe program defined by the Task Force includes two phases as listed in Figure VI-26. The first Preliminary Design phase encompasses focused technology on special problems and local structure areas guided by design activity. The second phase, Major Component Ground Tests, involves detailed design, fabrication, test, and comparison of test and predicted results for a major fuselage assembly.

PHASE I - PRELIMINARY DESIGN

Two parallel preliminary design studies will be initiated early in this program phase (Figure VI-27) of advanced airframe configurations for medium sized helicopters (15,000 to 20,000

pound gross weight). The configurations will incorporate advanced composite materials to the maximum extent practicable, and will aim for a 50 percent reduction in parts count compared to the current state of the art. The designs will take into account significant data which may have become available from the first series of in-service flight loads and environment data gathering under the Vibration program. The preliminary designs will, in particular, give attention to the design of joints and fittings to carry large high frequency vibratory loads, to efficient use of composite ply orientation and structural reinforcement concepts to effectively manage load paths around large cutouts, to the effective use of composites for controlling transmission of vibration and noise, and to provision of crashworthiness approximately equivalent to that of current conventional fuselages. Developmental tests will be planned and executed as part of the preliminary design activity to generate design data and to validate the design concepts, design premises and fabrication procedures, as well as to demonstrate potential payoffs of advanced composite primary structures. It is expected that the test speciments will range from small tension/compression coupons to large segments of potential airframe configurations subjected to complex loading conditions.

PHASE II - MAJOR COMPONENT GROUND TESTS

In this phase (Figure VI-28), a major airframe component such as a center fuselage, aft fuselage, roof segment, or belly segment will be selected for detailed design, fabrication and ground testing as proof of concept and partial design validation of the preliminary design effort. The ground testing will include both static and dynamic tests. It is intended that static testing be carried to failure in order to establish ultimate strength characteristics. Dynamic testing will include scale tests to correlate with design predictions of vibration modes and frequencies, and drop tests to validate crashworthiness design goals.

COMPOSITE AIRFRAME PROGRAM SUMMARY

The time phasing of the Composite Airframe program key task areas is summarized in Figure VI-29.

TOTAL ROTORCRAFT SYSTEMS ANALYSIS MODELING

As outlined in the Aerodynamics and Structures Program elements above, advances in the primary/analyses/predictive design methodology areas will be addressed in the areas of vibrations, aeroelastic stability, stability and controls, performance, loads and acoustics. Ideally, these predictive programs will be directed toward implementation in advanced versions of currently conceived executive/software systems for industrywide use. They will include formulation and programming development of technically sophisticated theories for use within the design community. The basis for the program modules are generic; that is, they interpret the physics of the phenomena in such a way as to be applicable to all rotor systems including teetering, articulated, rigid, etc. Further, they must be capable of handling advances in finite element modeling, aerodynamic theory or structures (such as anisotropic materials). Within the various design methodologies (aero/acoustics, vibration reduction, and composites) the rotorcraft software programs will be validated through systematic correlation with detailed tests.

AERODYNAMICS AND STRUCTURES

PROGRAM THRUSTS

AERO/ACOUSTICS

VIBRATION

COMPOSITE AIRFRAME

FIGURE VI-1

AERO/ACOUSTICS

PURPOSE

PROVIDE DESIGN METHODOLOGY AND VALIDATING DATA BASE TO SUSTAIN ORDERLY DEVELOPMENT OF HELICOPTER DESIGNS TO ATTAIN FUTURE STRINGENT NOISE AND PERFORMANCE STANDARDS

GOALS

AERO/ACOUSTICS DESIGN METHODOLOGY AND DATA BASE FOR IMPROVED HELICOPTER DESIGNS THAT

- REDUCE NOISE BY 5-10 dB
- IMPROVE HOVER EFFICIENCY BY 10%
- IMPROVE CRUISE EFFICIENCY BY 20%

FIGURE VI-2

AERO/ACOUSTICS
PROGRAM APPROACH

PHASE I DESIGN METHODOLOGY DEVELOPMENT/VALIDATION

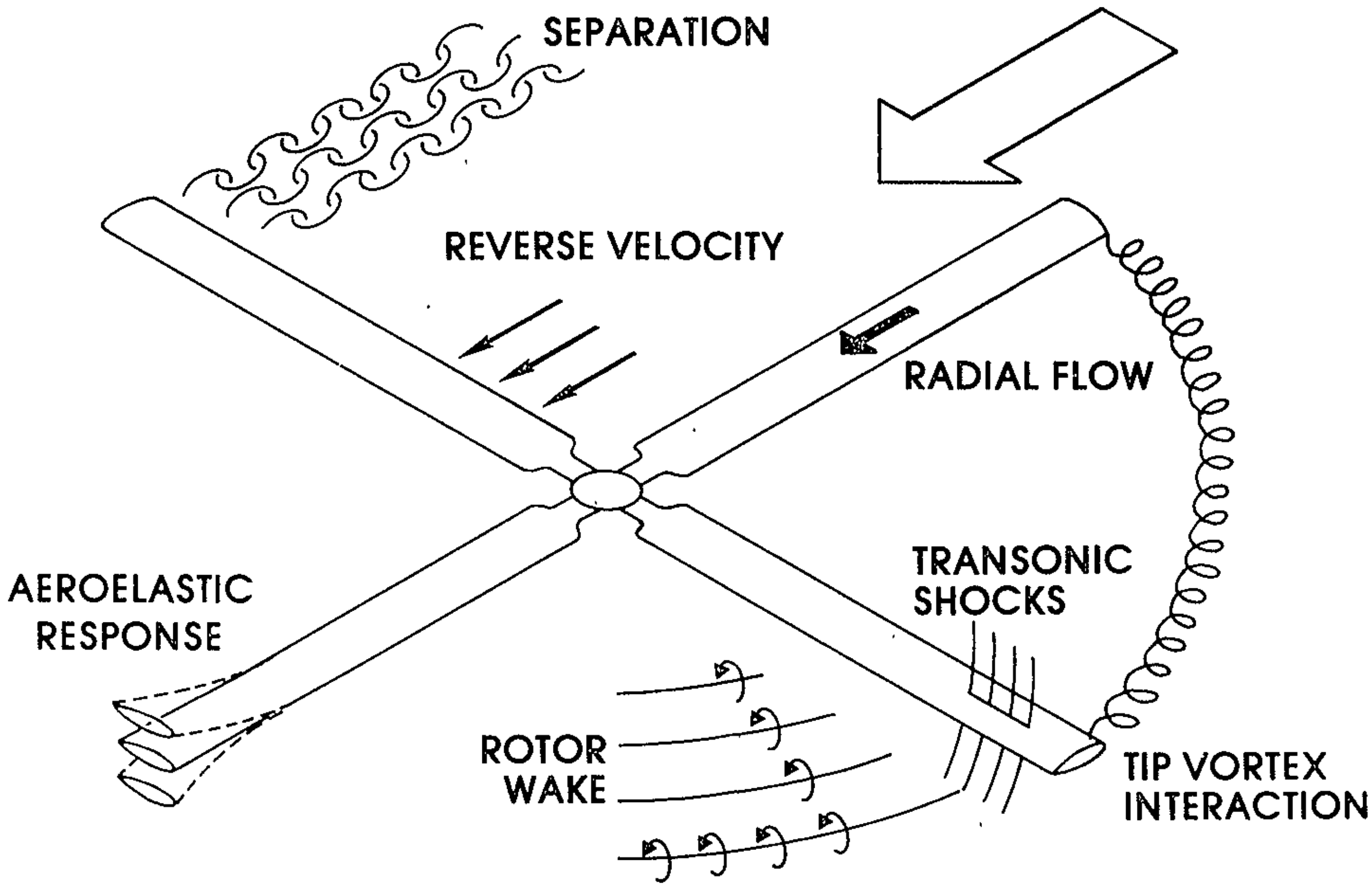
- ISOLATED ROTOR AERO/ACOUSTICS
  - COMPREHENSIVE SUB- AND LARGE-SCALE TUNNEL TESTS OF ROTOR FAMILY (3)
  - DESIGN PREDICTION ANALYSES
- ROTOR/AIRFRAME AERO/ACOUSTICS
  - COMPREHENSIVE TESTS OF ONE CONFIGURATION
    - SUB- AND LARGE-SCALE TUNNEL MODELS
    - FLIGHT TEST
    - DESIGN PREDICTION METHODS

PHASE II 2ND GENERATION ROTOR AERO/ACOUSTIC PREDICTION/VALIDATION

- DESIGN STUDIES/PREDICTIONS
- GROUND-BASED AND FLIGHT TESTS
- REFINED PREDICTION METHODS

FIGURE VI-3

AERO/ACOUSTICS
COMPLEX ROTOR FLOWS

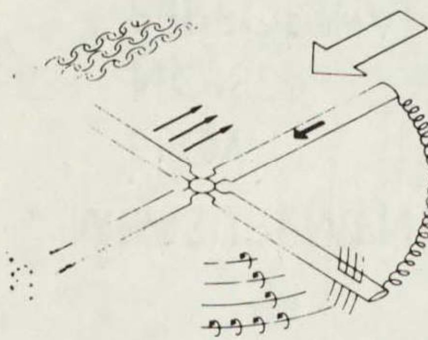


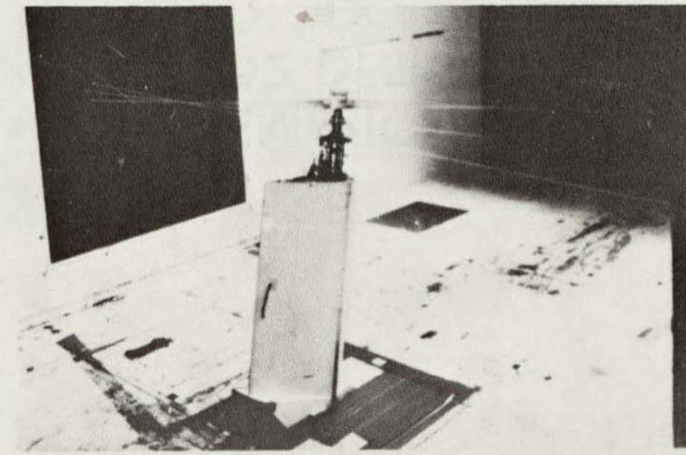
PROBLEM: Existing Rotor Prediction Methods Totally Inadequate for Aero/Acoustic Design

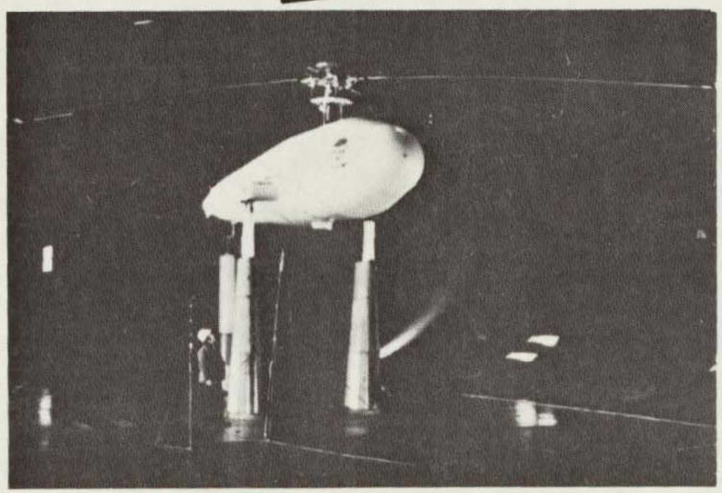
FIGURE VI-4

AERO/ACOUSTICS

ROTOR DESIGN METHODOLOGY







ROTOR FAMILY
DATA BASE

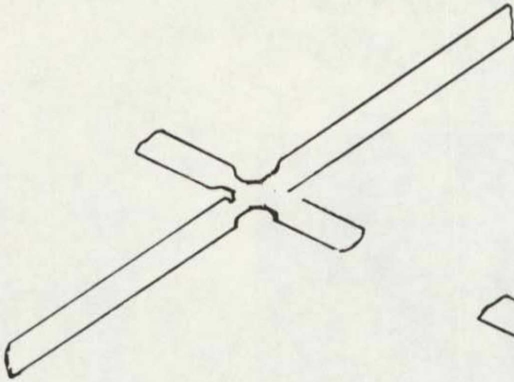
FLOW AND NOISE
ANALYTICAL STUDIES

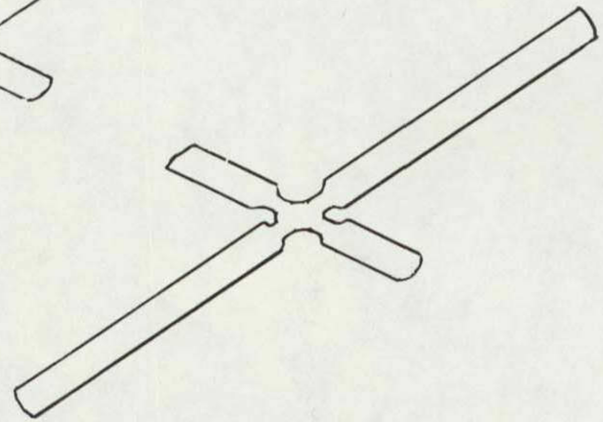
VALIDATED ROTOR
AERO/ACOUSTIC DESIGN
PREDICTION METHODS

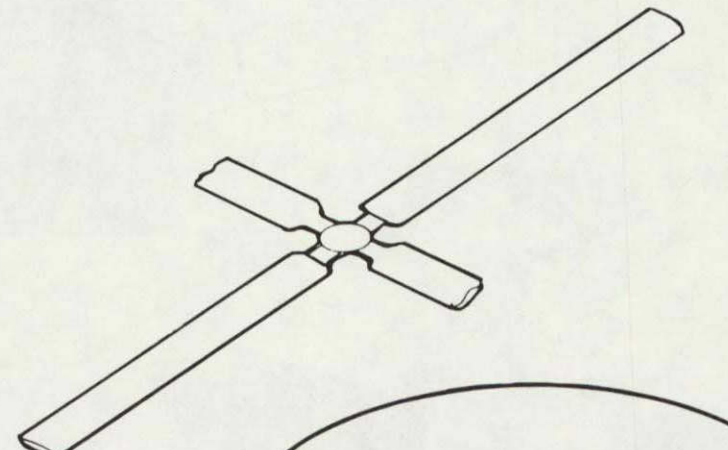
FIGURE VI-5

AERO/ACOUSTICS

ROTOR DATA BASE







ROTOR TEST FAMILY

FIXED	VARIED
AIRFOIL TYPE	TWIST
CHORD	THICKNESS
DIAMETER	TIP SHAPES
4 BLADES	DESIGN C_L

MEASUREMENTS

FLOW
NOISE
PERFORMANCE
LOAD

SMALL SCALE
LARGE SCALE

SYSTEMATIC DATA FOR DESIGN METHODOLOGY

FIGURE VI-6

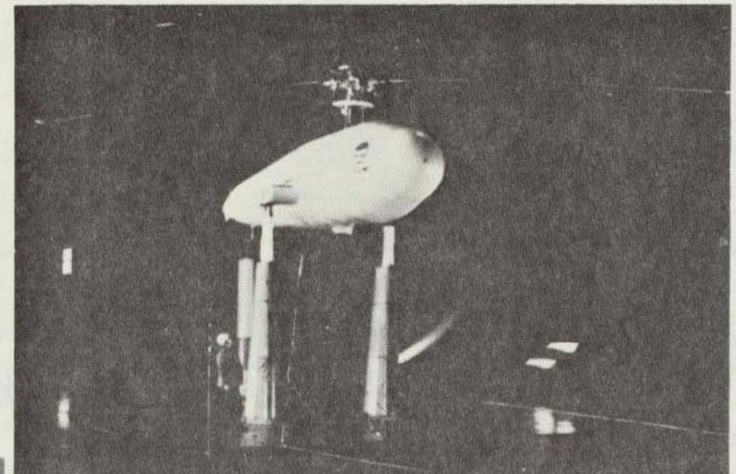
AERO/ACOUSTICS

ROTOR SCALE MODELING

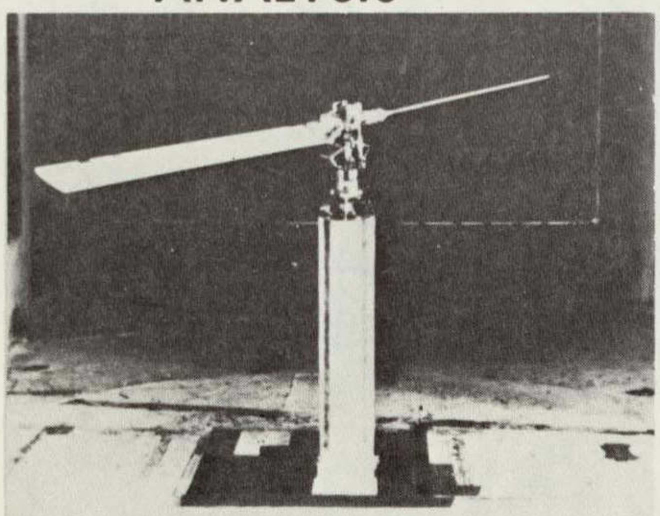
ROTOR FAMILY TESTS

- THREE ROTORS
- SMALL SCALE
- LARGE SCALE

SCALE MODELING ANALYSIS



LARGE SCALE



SMALL SCALE

SMALL → LARGE SCALE EFFECTS DATA BASE

VALIDATED METHODS FOR ROTOR SCALE MODELING

FIGURE VI-7

AERO/ACOUSTICS
ROTOR FLOW ANALYSIS

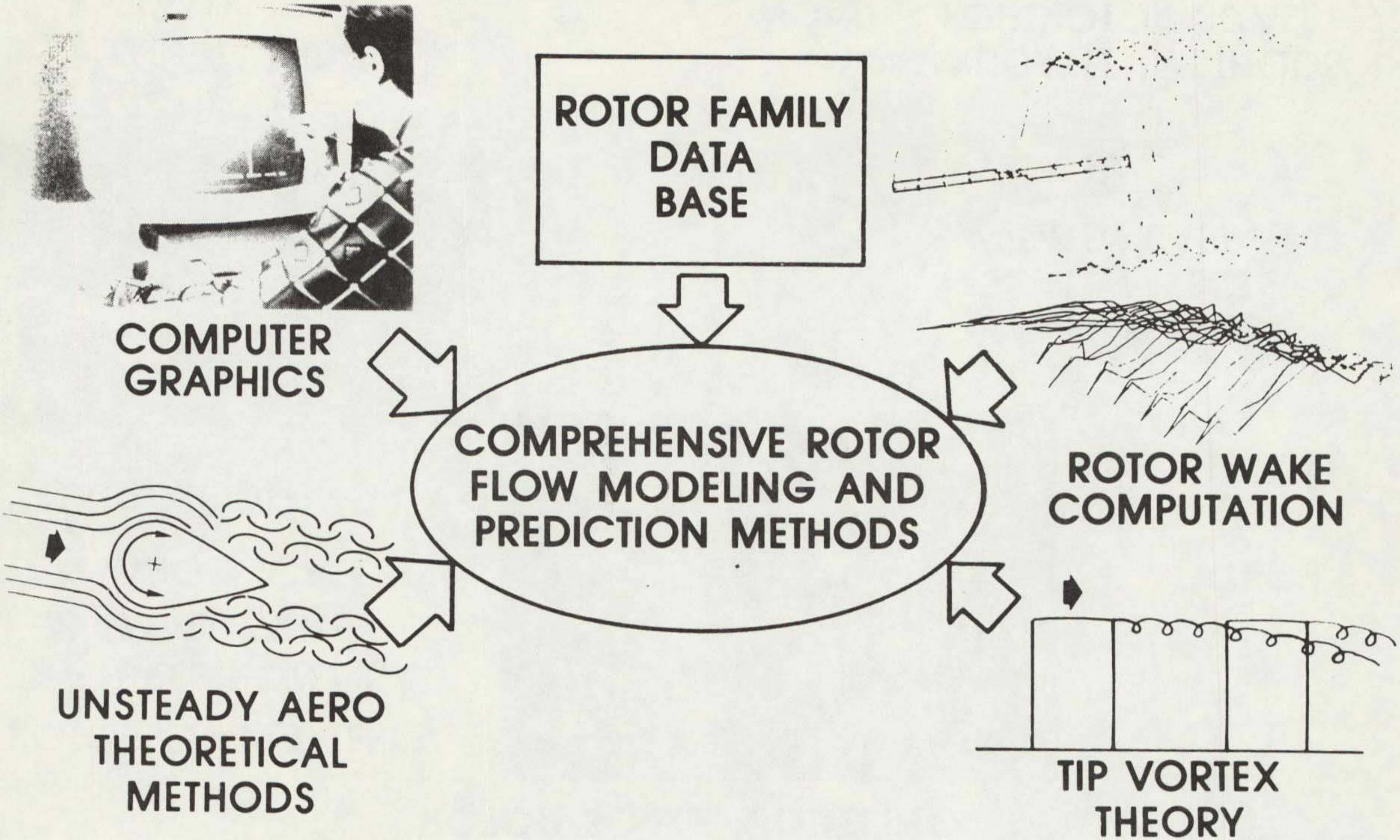


FIGURE VI-8

AERO/ACOUSTICS
ROTOR ACOUSTICS

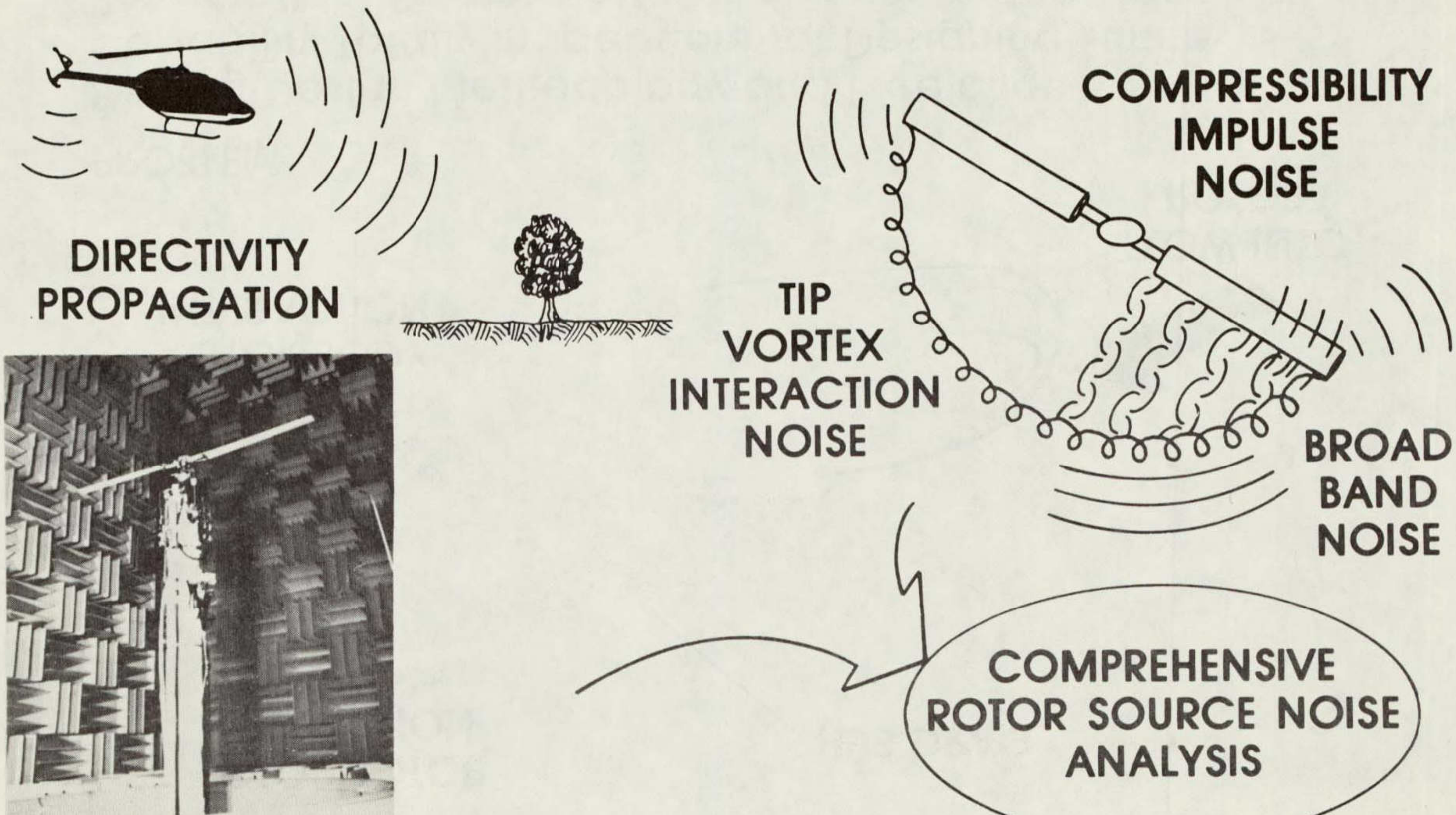
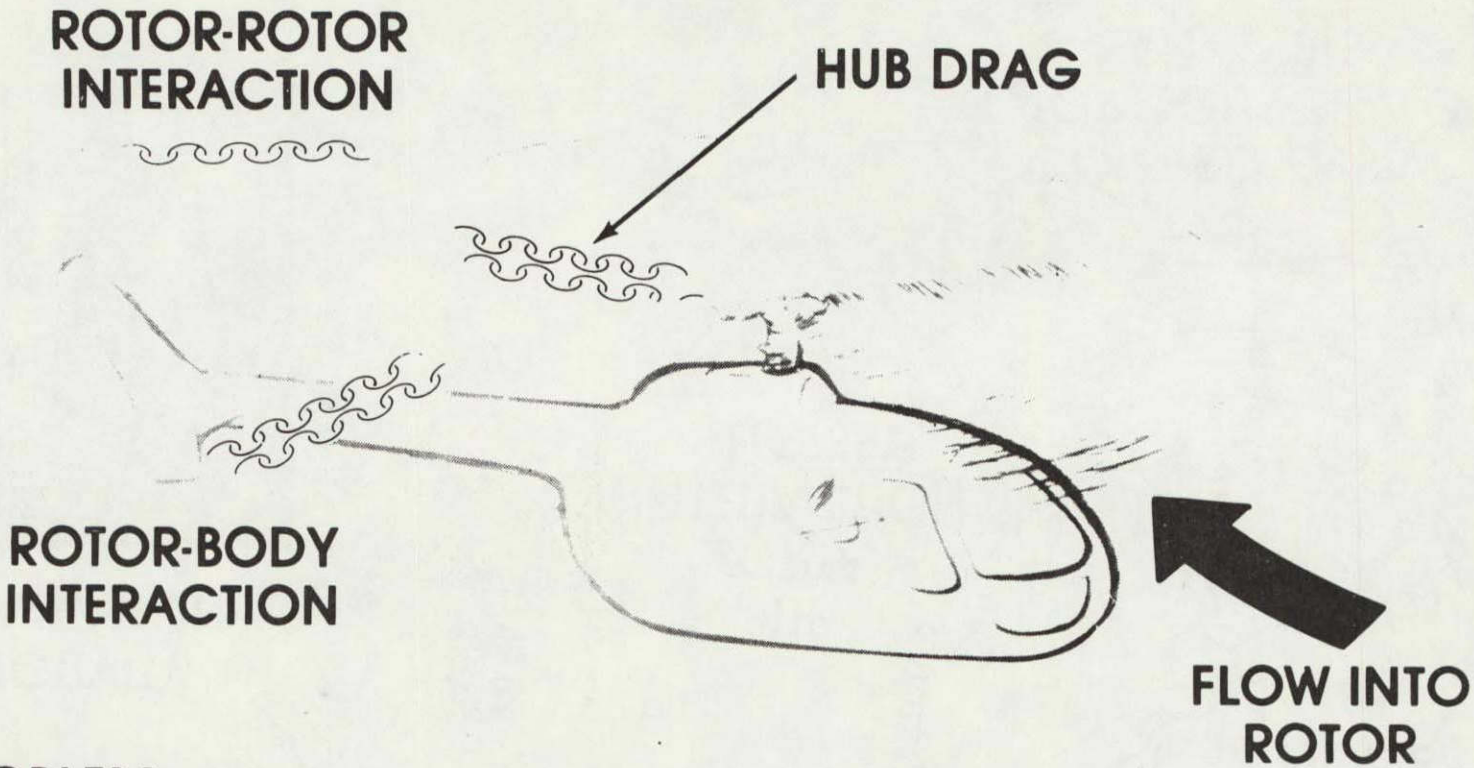


FIGURE VI-9

AERO/ACOUSTICS

ROTOR/AIRFRAME INTERACTIONS



PROBLEM:

Existing Design Methodology and Prediction Capability Totally Inadequate for Designing Future Rotorcraft for Stricter Noise and Performance Standards.

FIGURE VI-10

AERO/ACOUSTICS
ROTOR/AIRFRAME DESIGN METHODOLOGY

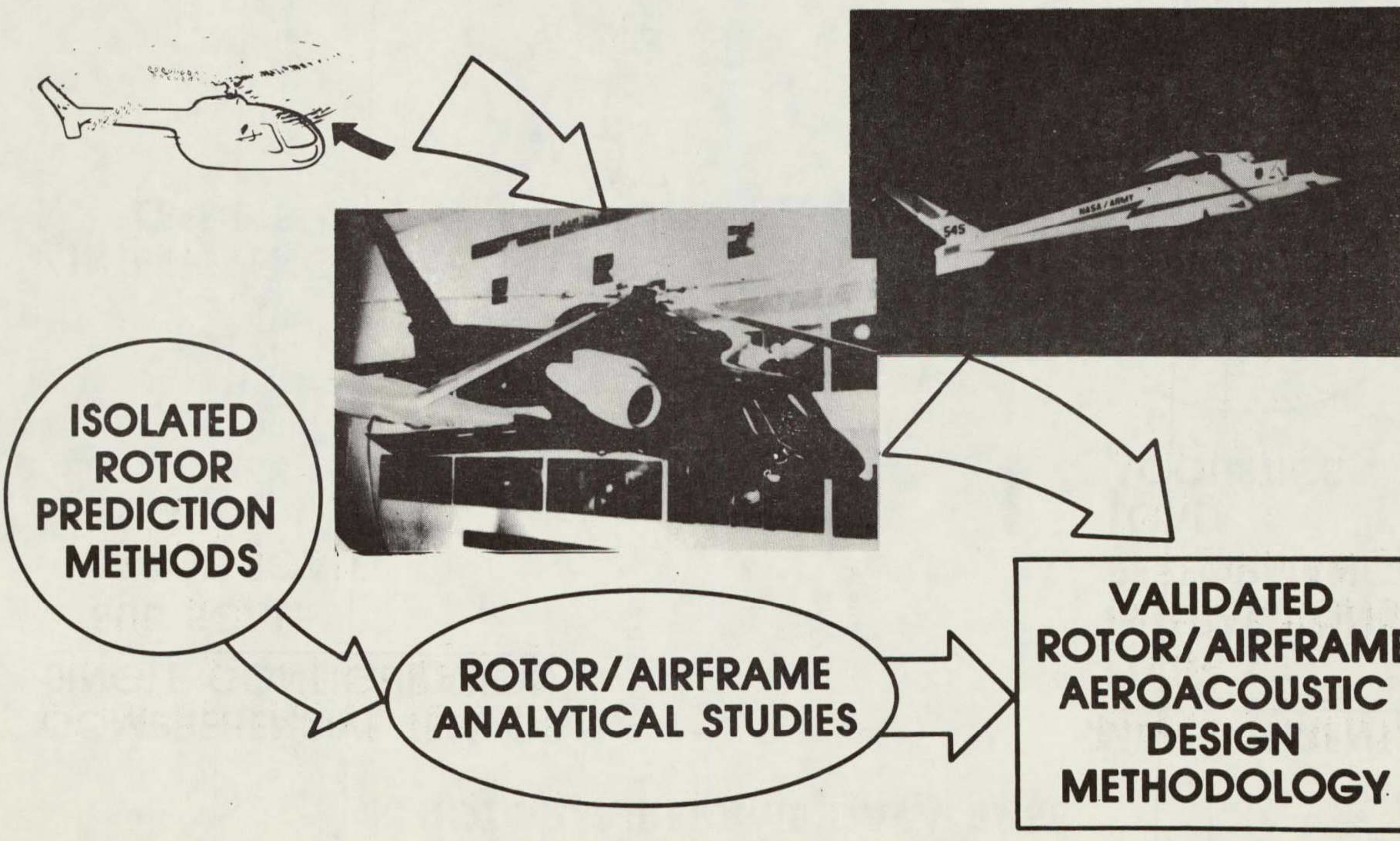


FIGURE VI-11

AERO/ACOUSTICS

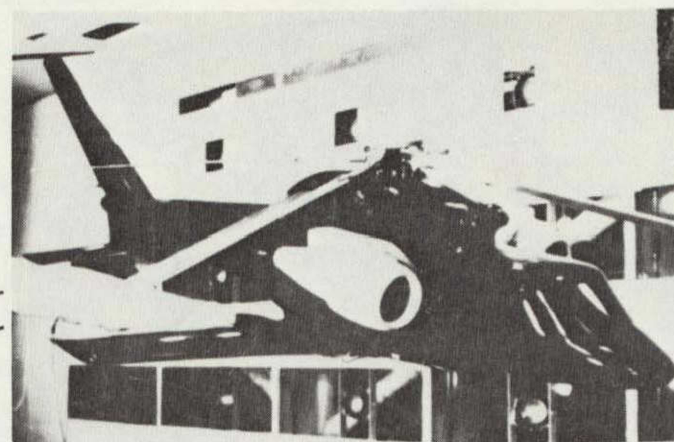
ROTOR/AIRFRAME DATA BASE

COMPREHENSIVE TEST OF SINGLE CONFIGURATION

SUB SCALE
LARGE SCALE
FLIGHT

MEASUREMENTS

FLOW
INTERACTIONS
PERFORMANCE
LOAD
ACOUSTICS



INTERFERENCE EFFECTS

DRAG REDUCTION

SCALE MODELING

SYSTEMATIC DATA FOR DESIGN METHODOLOGY

FIGURE VI-12

AERO/ACOUSTICS

SECOND GENERATION ROTOR AEROACOUSTIC PREDICTION AND VALIDATION

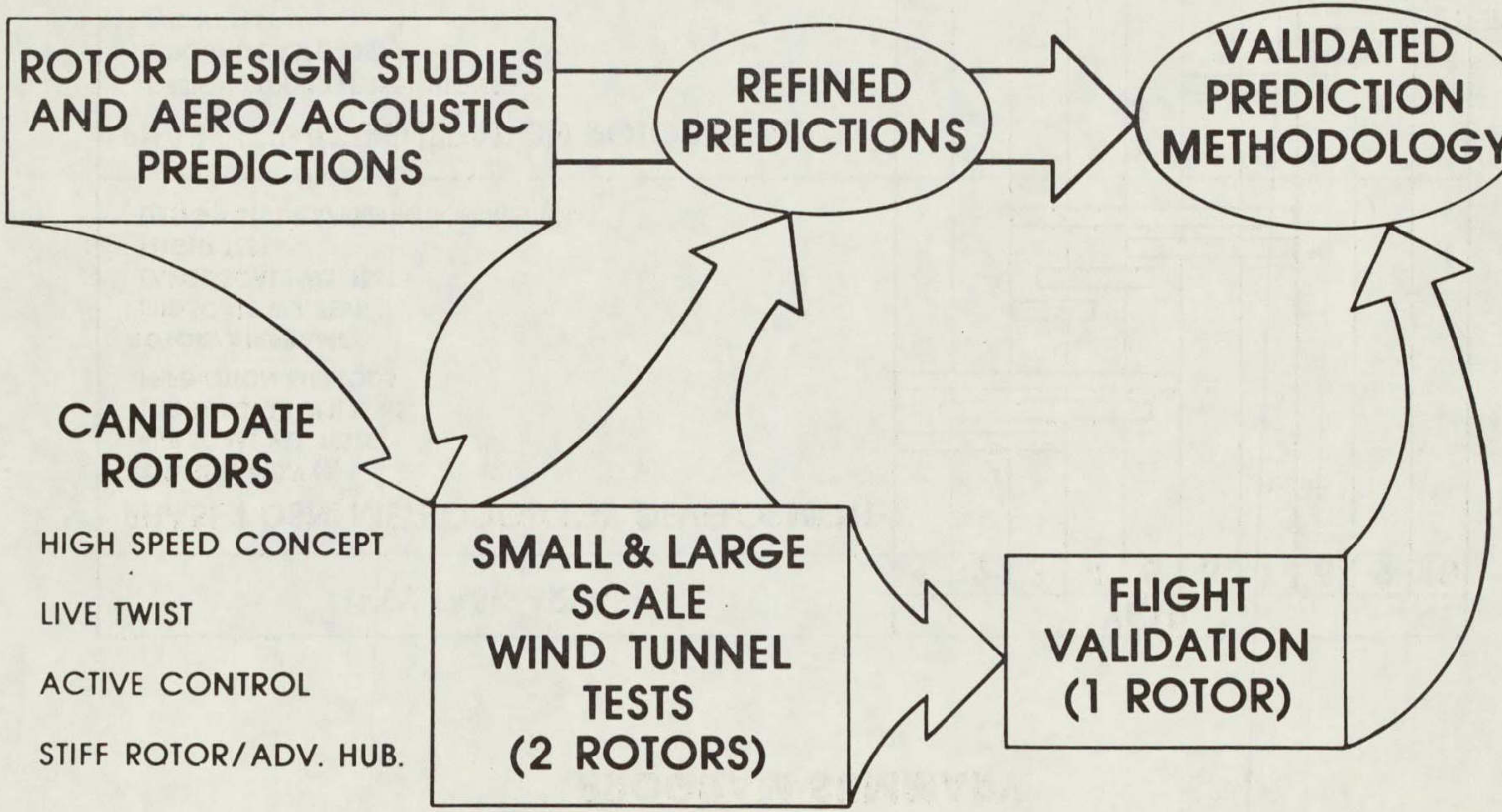


FIGURE VI-13

AERO/ACOUSTICS
PROGRAM SUMMARY

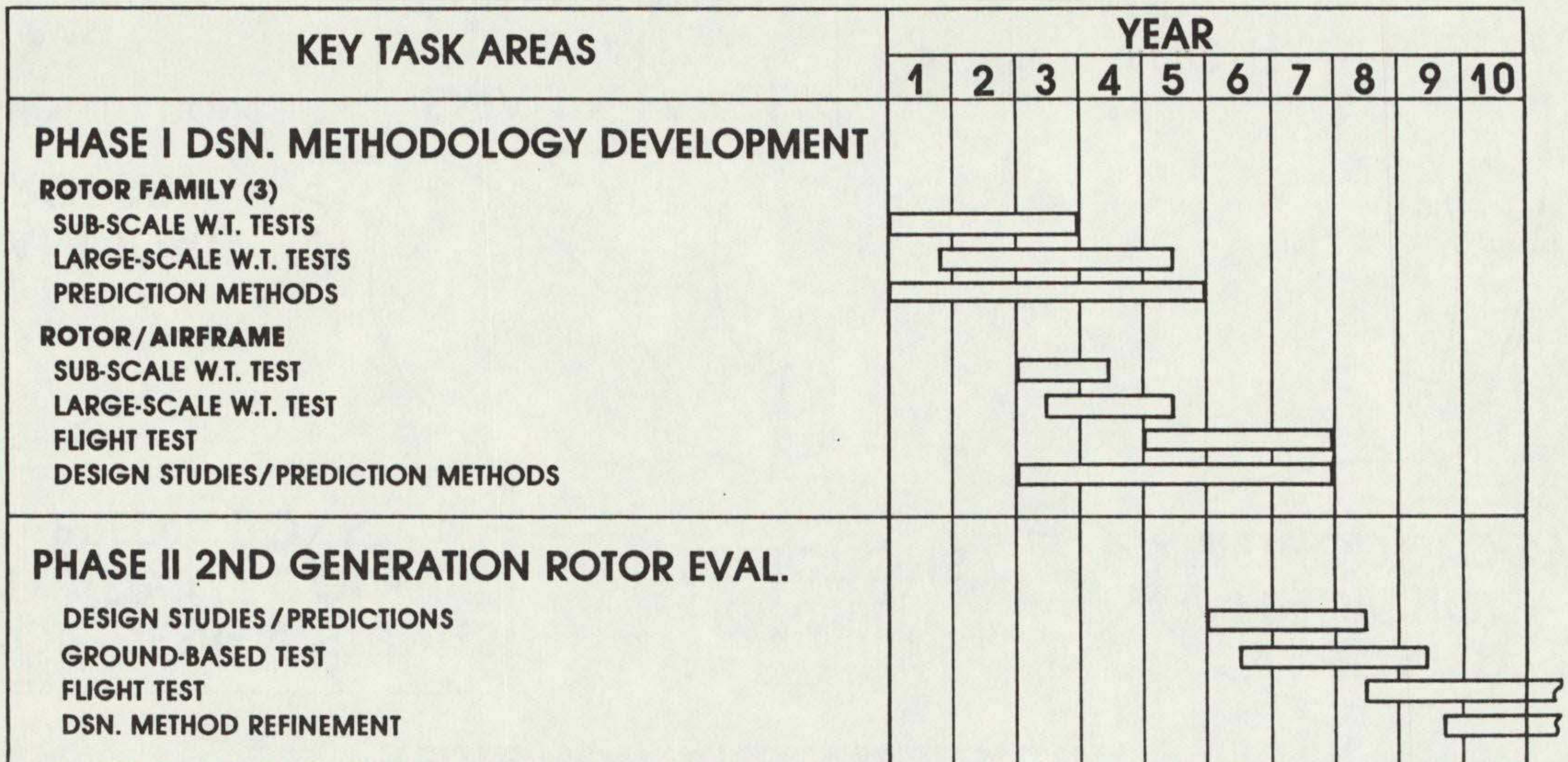


FIGURE VI-14

VIBRATION

PURPOSE

PROVIDE THE FOCUSED TECHNOLOGY & DESIGN METHODOLOGY FOR ACCURATE PREDICTION & SUBSTANTIAL REDUCTION OF AIRFRAME VIBRATION & INTERNAL NOISE

MAJOR EXTENSION HUB/ROTOR TECHNOLOGY

GOALS

VIBRATION AND INTERNAL NOISE PREDICTION METHODS WHICH ARE WIDELY ACCEPTED & USED BY HELICOPTER COMMUNITY

VIBRATION & NOISE APPROACHING COMFORT LEVELS OF FIXED WING TRANSPORTS

TECHNOLOGY FOR NEXT GENERATION HUB/ROTOR CONCEPTS

SIMPLICITY	⅔ FEWER PARTS
COST	10-50% LESS
VIBRATION	JET SMOOTH AT COCKPIT/CABIN
MTBR	INFINITE OR ON-CONDITION
WEIGHT	10-50% LESS

FIGURE VI-15

VIBRATION
PROGRAM APPROACH

PHASE I – **AIRFRAME LOADS & MODELING DESIGN METHODOLOGY**

IN-SERVICE FLIGHT LOAD & ENVIRONMENT MONITORING

AIRFRAME MODELING/TEST ASSESSMENT

VIBRATORY LOAD MODULES IMPROVEMENT/ VALIDATION

VIBRATION SUPPRESSION BY ACTIVE CONTROLS

INTERNAL NOISE SUPPRESSION

PHASE II – **ADVANCE HUB/ROTOR DESIGN METHODOLOGY**

DESIGN ANALYSIS

SELECTED FABRICATION & GROUND-BASED TEST/EVALUATION

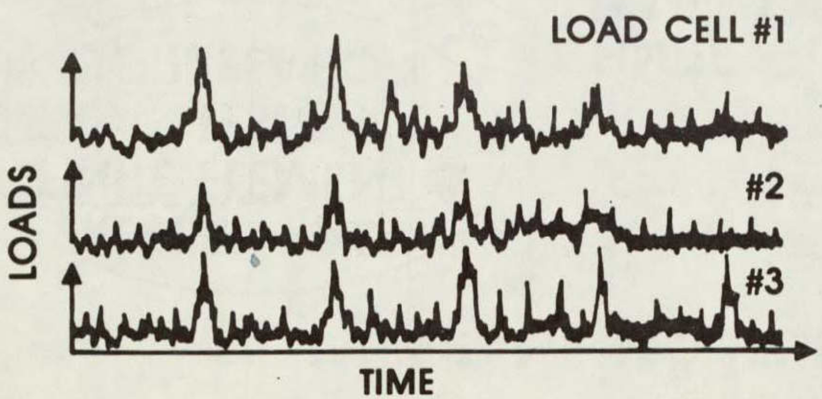
PHASE III – **FLIGHT VALIDATION OF ADVANCED HUB/ ROTOR SYSTEM**

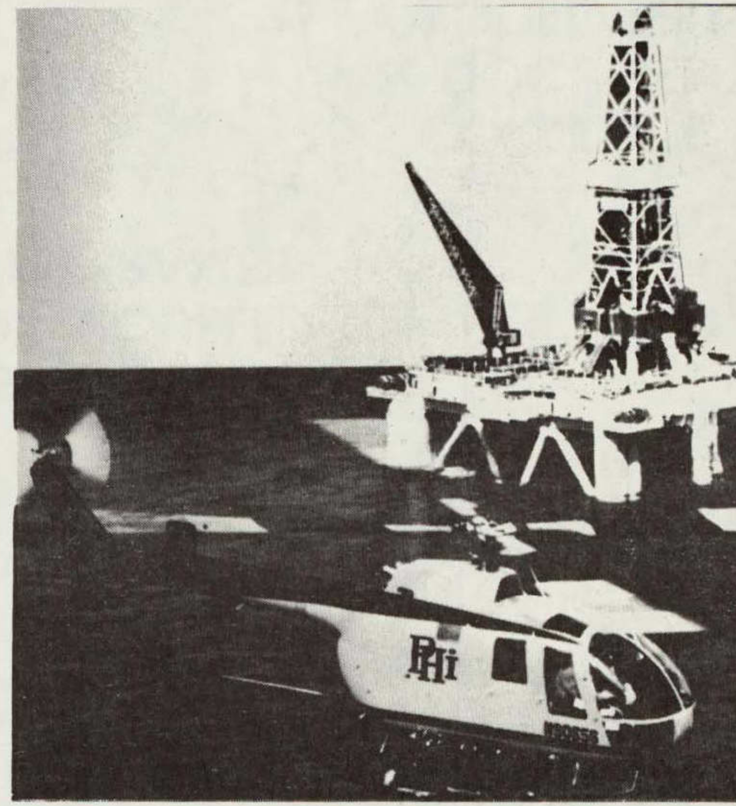
FIGURE VI-16

VIBRATION
IN-SERVICE FLIGHT LOAD AND ENVIRONMENT MONITORING

APPROACH

- MONITOR A RANGE OF CIVIL OPERATIONS
- INSTALL SENSING, MEASURING EQUIPMENT
- RECORD LOAD, ATMOSPHERIC, ENVIRONMENT DATA





GOAL

- OBTAIN LOAD AND ENVIRONMENT DATA BANK FOR CIVIL DESIGN CRITERIA

FIGURE VI-17

VIBRATION

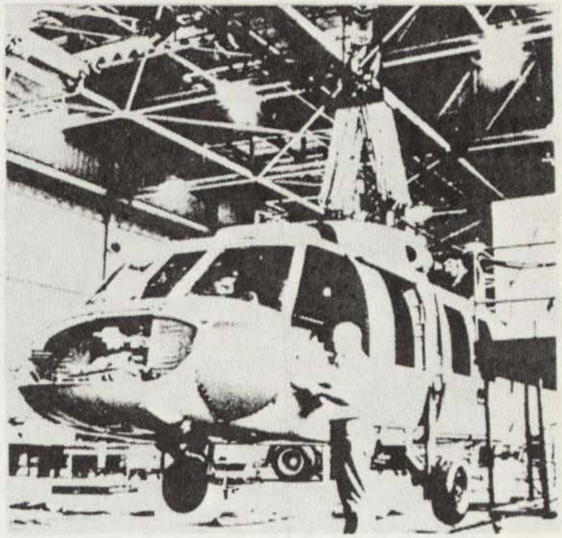
AIRFRAME MODELING/TEST ASSESSMENT

REVIEW PAST FINITE ELEMENT & TEST CORRELATION

FINITE ELEMENT ANALYSIS OF TWO AIRFRAMES BY NASA/INDUSTRY TEAM

SHAKE TESTS OF MODELED AIRFRAMES

CORRELATE & DOCUMENT MODEL/TEST GUIDELINES



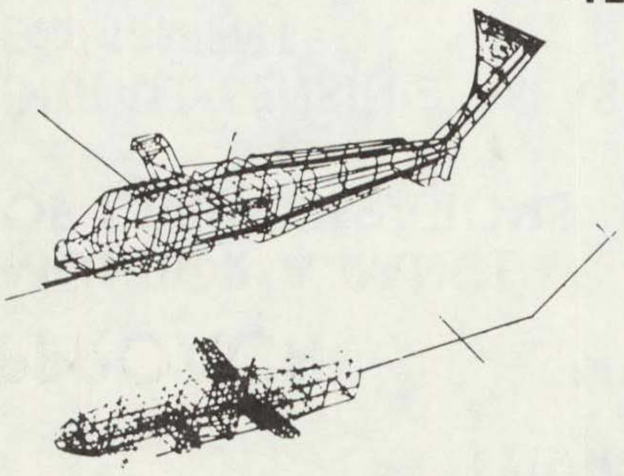
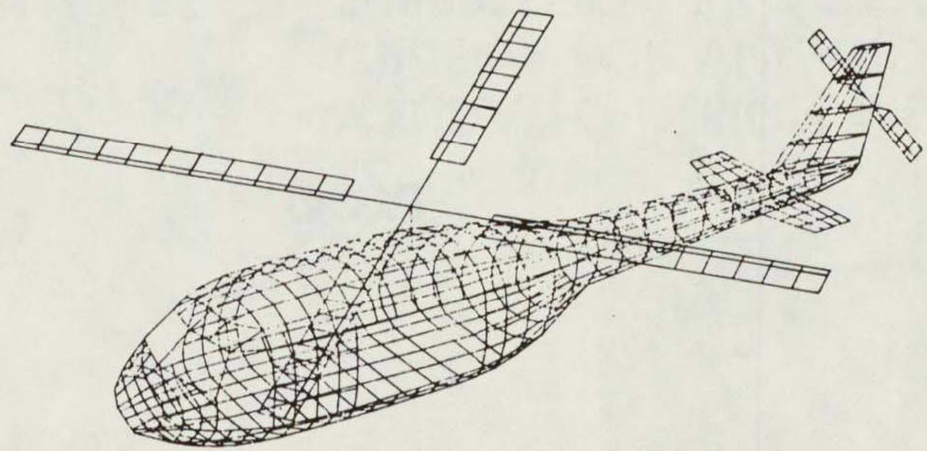


FIGURE VI-18

VIBRATION

AIRFRAME MODELING & TEST VALIDATION



APPROACH

EXTEND FINITE ELEMENT CAPABILITY

- COMPOSITES
- OPTIMIZATION

PROVIDE PREDICTION MODULES FOR HELICOPTER SOFTWARE SYSTEMS

PERFORM TEST VALIDATIONS ON AIRFRAME SECTIONS

REFINE PREDICTION MODULES

GOAL

IMPROVE VIBRATION PREDICTION CAPABILITY

- ACCURACY
- QUICK RESPONSE
- FLEXIBLE, GENERAL PURPOSE

FIGURE VI-19

VIBRATION

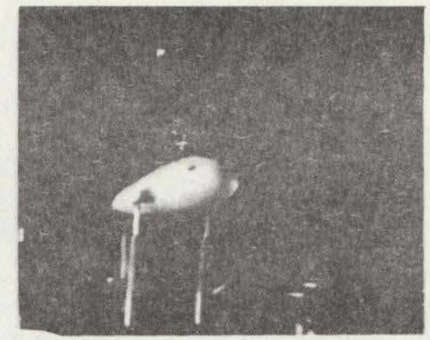
VIBRATION SUPPRESSION WITH ACTIVE CONTROLS

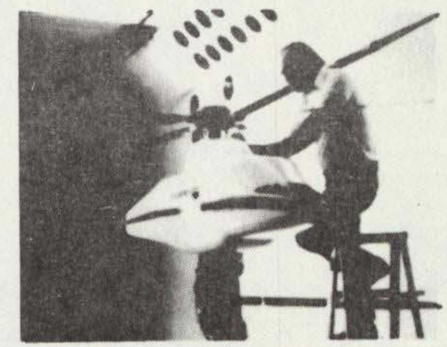
APPROACH

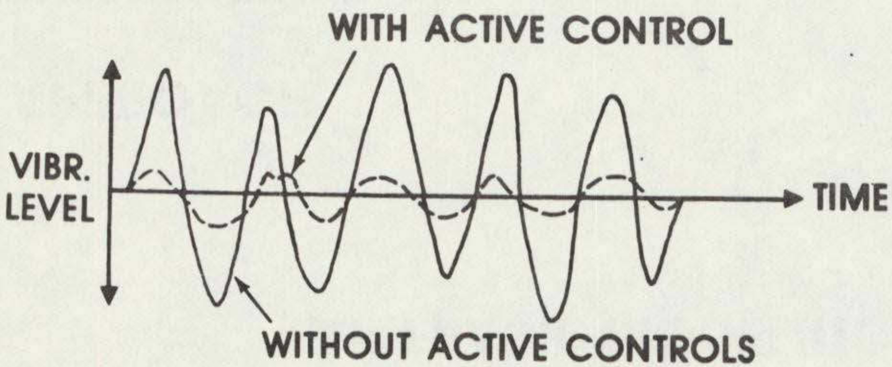
CONCEPTUAL DESIGN STUDIES
PREDICT VIBRATIONS

FULL- & SUB-SCALE MODEL TESTS

CORRELATE TEST RESULTS
WITH PREDICTIONS &
REFINE PREDICTION METHODS







GOAL

VALIDATED DESIGN METHODS/
CRITERIA FOR VIBRATION
SUPPRESSION BY ACTIVE
CONTROLS

FIGURE VI-20

VIBRATION

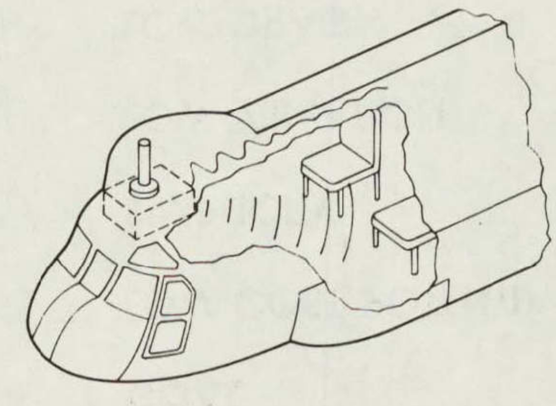
CABIN/COCKPIT NOISE SUPPRESSION

APPROACH

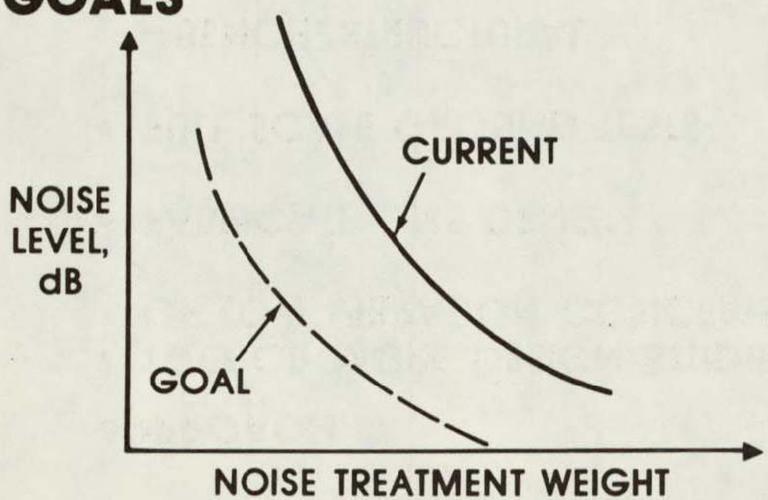
IMPROVE PREDICTION METHODS

VERIFY PREDICTIONS BY TEST

DEVELOP DESIGN CRITERIA FOR METHODS TO ATTENUATE INTERNAL RADIATED NOISE



GOALS



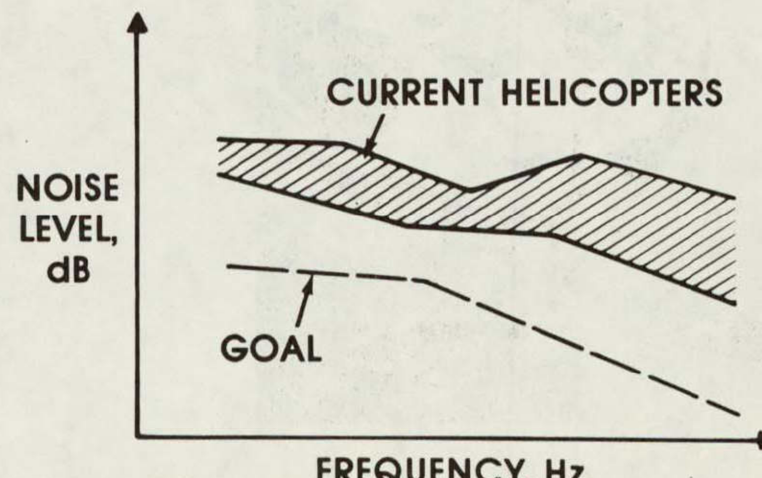
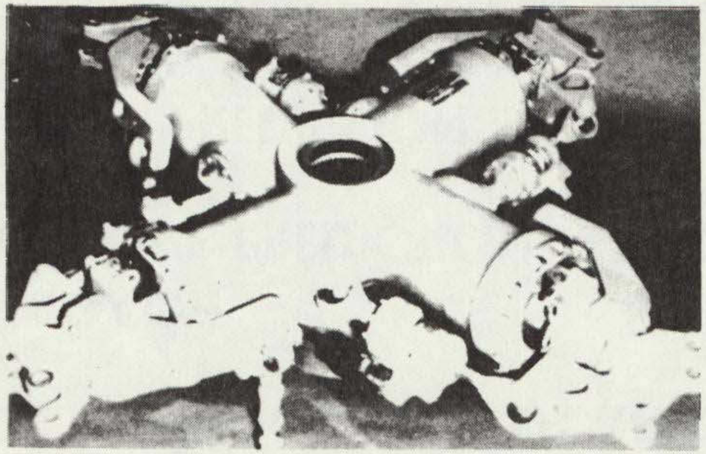


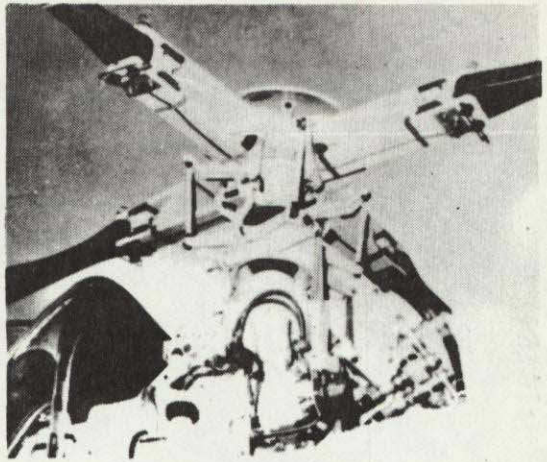
FIGURE VI-21

VIBRATION
ADVANCED HUB/ROTOR DESIGN METHODOLOGY

APPROACH

- TWO OR MORE DESIGN STUDIES OF LOW VIBRATION CONCEPTS
- FABRICATE ONE DESIGN
- FULL SCALE GROUND TESTS
  - BENCH/STRUCTURAL
  - 40 x 80-FT WIND TUNNEL
- EVALUTE/REFINE DESIGN CRITERIA





GOAL

LOW COST POTENTIAL

SIMPLICITY

LOW VIBRATION

LOW DRAG

REDUCED WEIGHT

FIGURE VI-22

VIBRATION
FLIGHT VALIDATION OF ADVANCED HUB/ROTOR

APPROACH

- REFINE HUB/ROTOR DESIGN FROM GROUND-BASED PROGRAM
- FABRICATE FLIGHT QUALIFIED HUB/ROTOR
- THOROUGHLY EVALUATE IN FLIGHT ENVIRONMENT
- REFINE DESIGN CRITERIA

GOALS

- DOCUMENTED DATA BASE IN DYNAMIC FLIGHT ENVIRONMENT TO CORRELATE WITH GROUND-BASED RESULTS
- FLIGHT VALIDATED DESIGN CRITERIA FOR SECOND GENERATION HUB/ROTOR CONCEPT

FIGURE VI-23

VIBRATION
PROGRAM SUMMARY

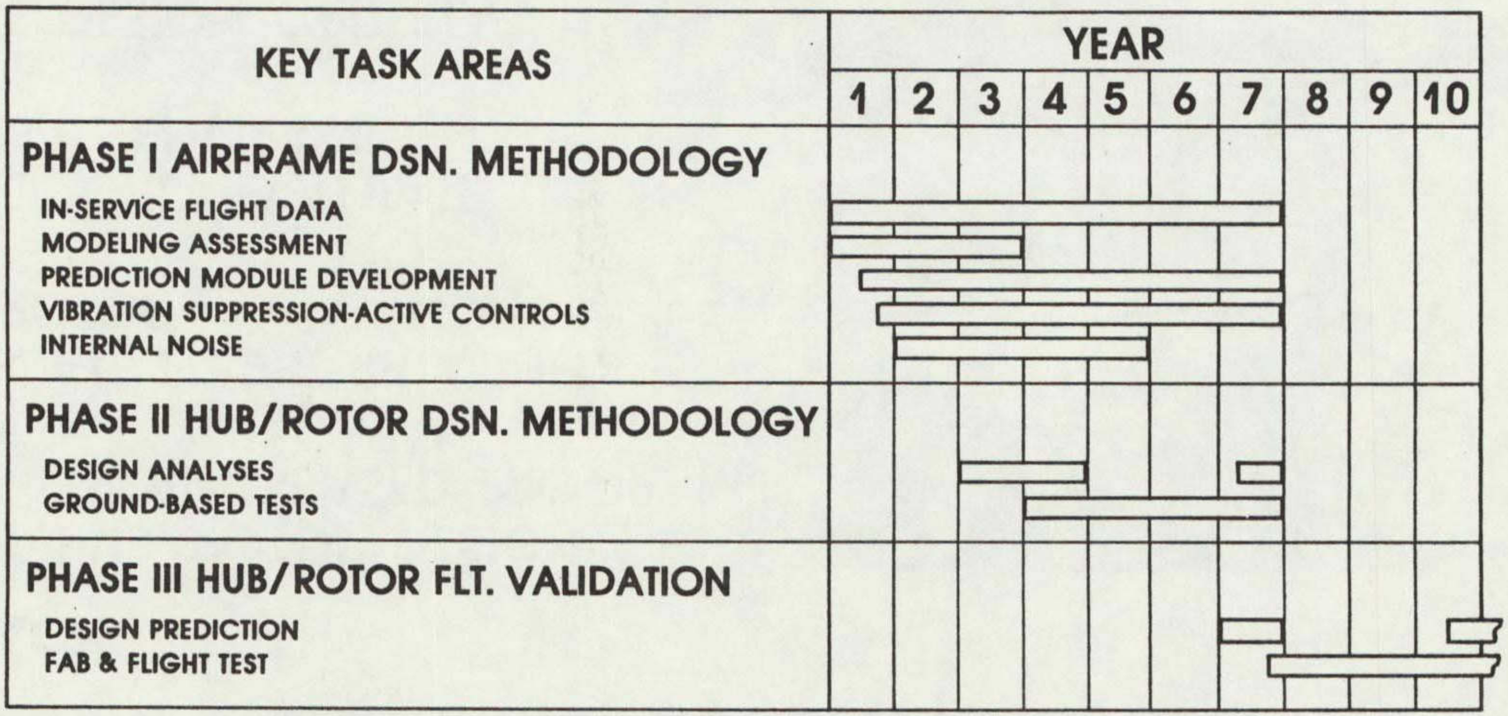


FIGURE VI-24

COMPOSITE AIRFRAME

PURPOSE:

DEVELOP ADVANCED DESIGN CONFIGURATIONS FOR HELICOPTER AIRFRAME STRUCTURE WHICH MAKE MAXIMUM USE OF ADVANCED COMPOSITES TO ACHIEVE LIGHT WEIGHT, REDUCED PARTS COUNT AND SIMPLER FABRICATION PROCEDURES.

GOAL/BENEFIT:

REDUCED ACQUISITION COSTS FROM REDUCED PARTS COUNT AND SIMPLER FABRICATION METHODS

PAYLOAD CAPABILITY INCREASED BY REDUCED STRUCTURAL WEIGHT

OPPORTUNITY FOR DESIGN INNOVATIONS TO ENHANCE CRASHWORTHINESS, DAMAGE TOLERANCE AND FATIGUE LIFE

FIGURE VI-25

COMPOSITE AIRFRAME
APPROACH

PHASE I—PRELIMINARY DESIGN

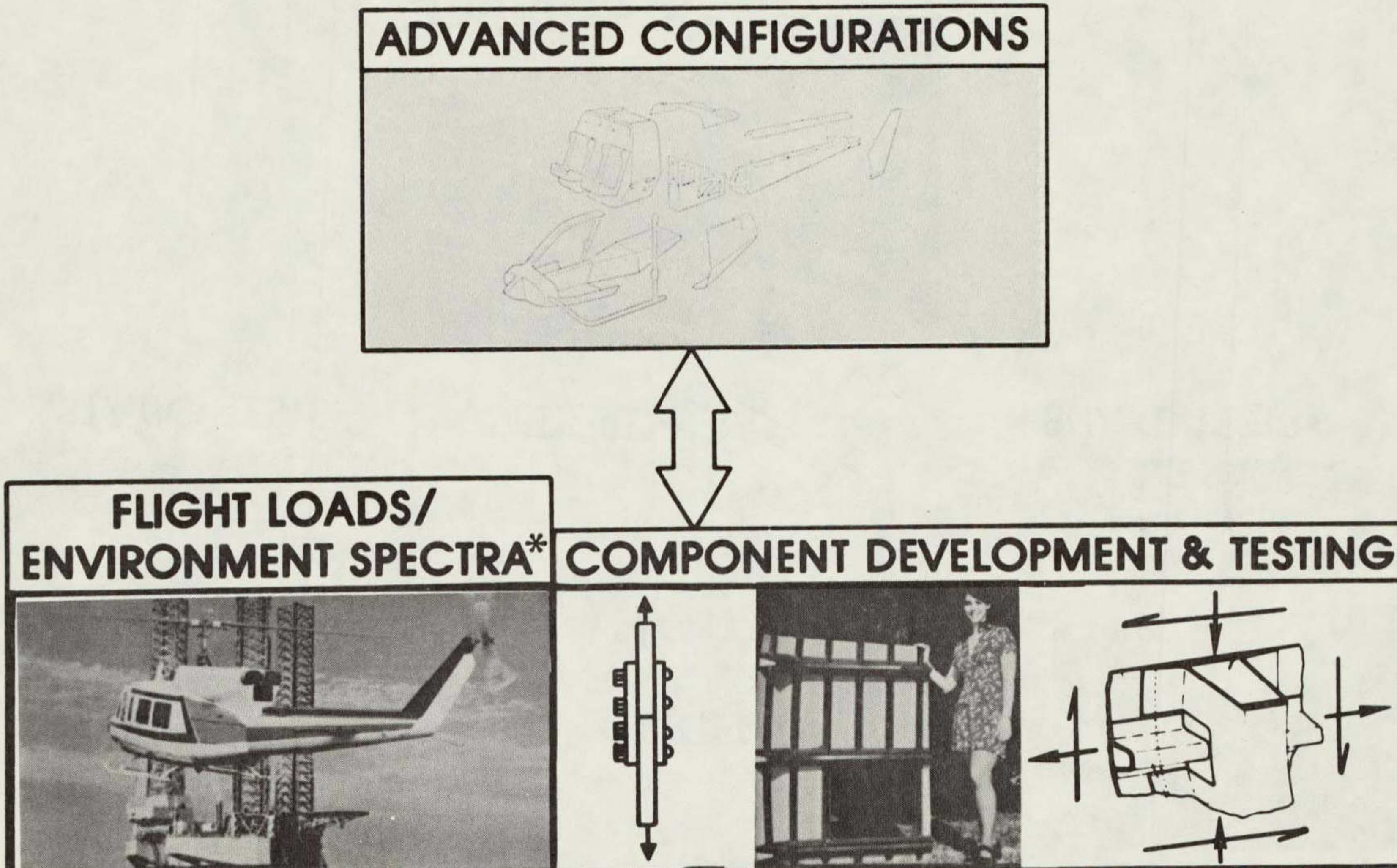
- CONFIGURATION CONCEPTS DEVELOPMENT
- IN-SERVICE FLIGHT LOADS DATA BASE
- IN-SERVICE ENVIRONMENTAL EFFECTS ON COMPOSITES
- JOINTS & FITTINGS DESIGN
- DEVELOPMENTAL TESTS OF COUPONS, COMPONENTS AND SUBCOMPONENTS

PHASE II—MAJOR COMPONENT GROUND TESTS

- MAJOR COMPONENT (E.G. CENTER FUSELAGE) SELECTION
- COMPONENT DETAIL DESIGN & FABRICATION
- COMPONENT GROUND TESTS & DESIGN VALIDATION

FIGURE VI-26

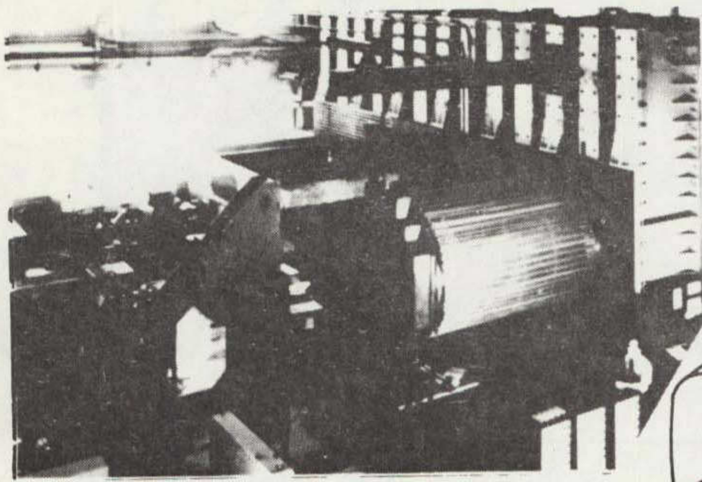
COMPOSITE AIRFRAME
PRELIMINARY DESIGN



*UNDER VIBRATION PROGRAM

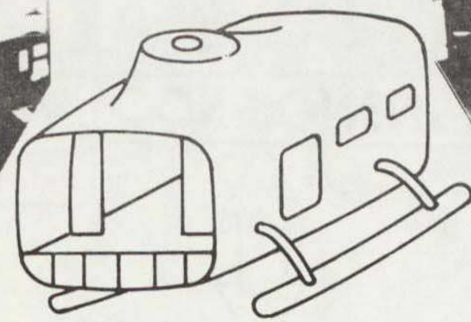
FIGURE VI-27

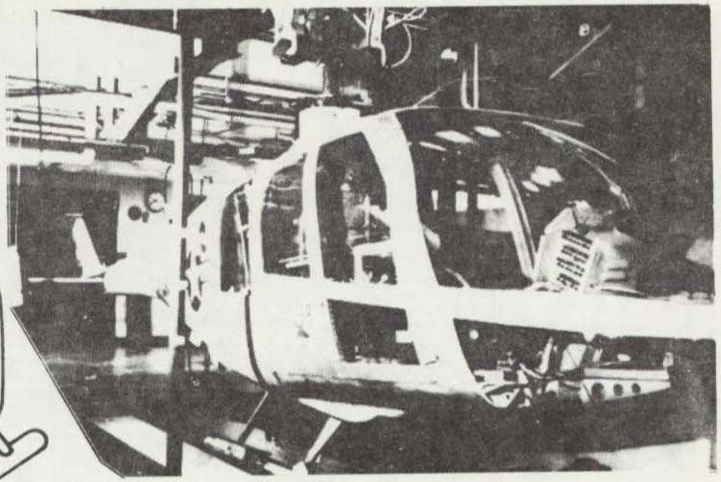
COMPOSITE AIRFRAME
MAJOR COMPONENT GROUND TESTS



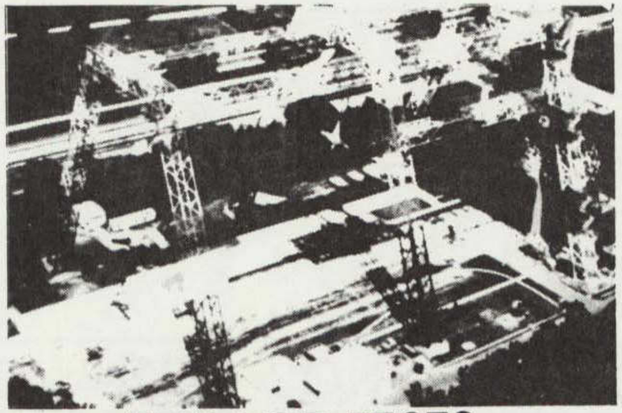
STATIC TESTS

CENTER FUSELAGE





SHAKE TESTS



IMPACT TESTS

FIGURE VI-28

COMPOSITE AIRFRAME
SUMMARY

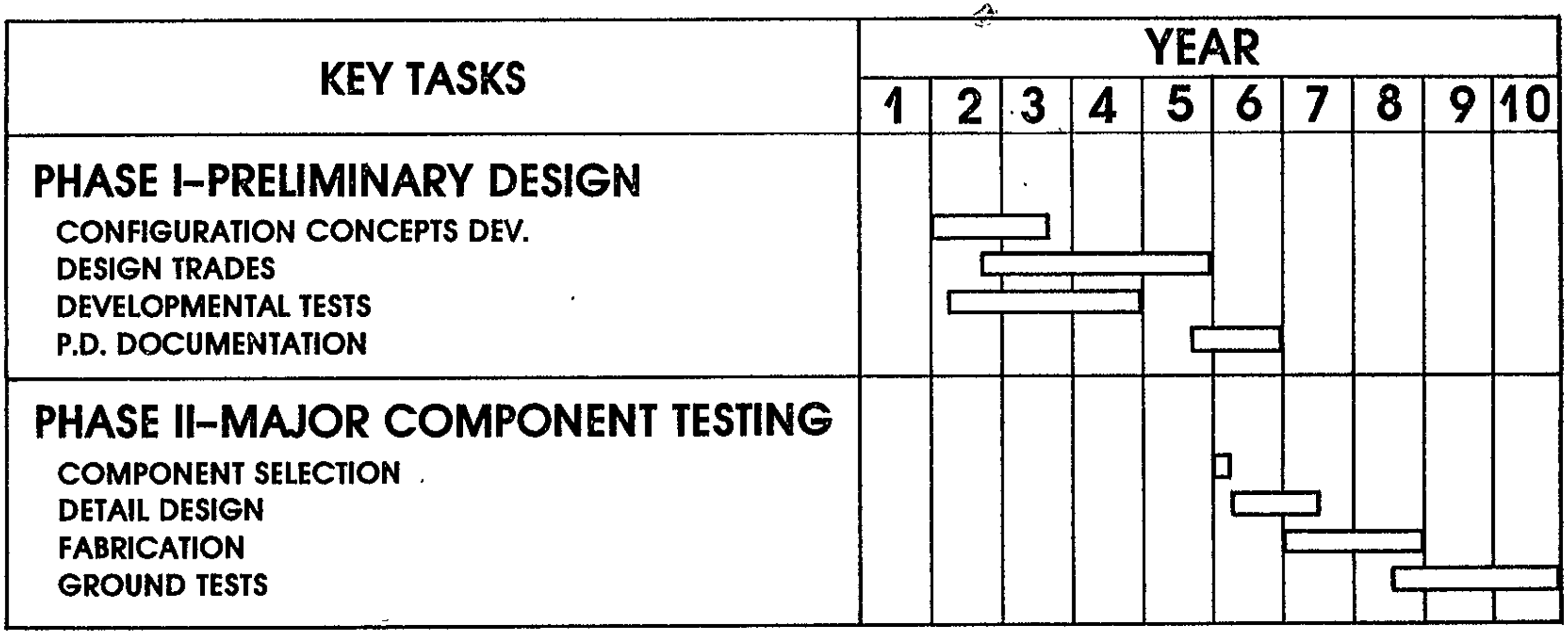


FIGURE VI-29

FLIGHT CONTROL AND AVIONIC SYSTEMS

Rotorcraft have unique vertical lift, vehicle dependent performance and control characteristics, and provide significant benefits over fixed wing aircraft only when these unique characteristics are effectively utilized. Consequently, there are growing demands and potential for rotorcraft flight control and avionics systems to provide improved performance, efficiency, reliability and handling qualities; pilot workload improvements; vibrations reduction; noise reduction, etc. To actually realize this potential will require fully integrated systems designs which properly interrelate rotor, propulsion, airframe/structures, flight control/avionic systems, handling qualities, and the man-machine interface.

The various trades between inherent aircraft stability and flight control augmentation stability systems; between fuel efficient mechanical engine designs and the use of electronic fuel control concepts; between optimization of airspace on precision closed loop flight control technology versus operating rotorcraft as "fixed wing" aircraft; the improvement of maintenance concepts based on systems monitoring to provide "on-condition" maintenance and overhaul; structural design limits versus full authority gust load alleviation and ride smoothing active control systems are but a few of the many examples that can be cited where high payoff can be obtained through improvement of flight control and avionic systems to meet unique rotorcraft systems performance and utilization demands.

The overall objective of this effort (Figure VII-1) in rotorcraft flight control and avionic systems is to draw from the broad based generic research in avionics and from ongoing vehicle specific research to significantly enhance the unique operating capabilities of advanced rotorcraft. It is in this context that key thrusts in all-weather rotorcraft operation and active control technology will be carried out. Some of the aircraft to be used in this program are illustrated in Figure VII-2. These aircraft are already, or soon will be, involved in ongoing operating systems flight research activities at the Ames Research Center.

ALL-WEATHER ROTORCRAFT OPERATION

PURPOSE: The purpose of this research (Figure VII-3) is to provide the critical technology to allow Instrument Meteorological Condition (IMC) rotorcraft operating performance comparable to performance under Visual Meteorological Conditions (VMC).

BENEFITS: The primary benefits (Figure VII-3) will be validated systems technology and operating techniques which will provide safe IMC operations for remote sites and high density terminal areas.

Specifically, for the remote sites, the goal is to provide IMC capability (based on on-board systems) down to decision heights as low as 100 feet. Considerable progress has been made for operating into offshore remote sites and this will be extended to provide the specific goal mentioned above. On the other hand, little experience has been obtained relative to decision heights of 100 feet for on-shore remote sites where terrain problems are so much more severe than in the case of over-the-water approaches to offshore oil rigs.

For the high density terminal operations case the specific goal is to provide systems technology and operating techniques for IMC operations down to decision heights less than 50 ft. (based on using terminal area navigation and guidance aids). Systems technologies will be developed and validated with emphasis on improved utilization of airspace through use of 3D/4D techniques. Now, helicopters are often required to fly fixed wing approach patterns. Improved utilization of fuel will also be emphasized.

JUSTIFICATION: Improved IMC capabilities are key to continuing the rotorcraft growth and improvement of national benefits associated with resources exploration/development/management, executive air transportation, construction, lumbering, and public services.

PROGRAM: The research program will be based on needs, requirements, and operating experience of the users, in coordination with the FAA, industry, and the users. Systems concepts will be defined, constructed and evaluated through simulations, controlled flight research under highly instrumented conditions and operational flight assessments. There are two main all-weather rotorcraft system technology thrusts (Figure VII-4). These are remote sites "on-board" systems technology and high density 3D/4D guidance, including air traffic control interfacing and integrated Category III systems technology. Key advanced stabilization and control systems technologies, needed for both all-weather and active control systems concepts, will be addressed in the initial phase of this program element.

<u>Remote Sites "On-Board" Systems Technology</u>

"On-board" Systems Technology (Figure VII-5) will be developed and validated for IMC approach guidance and navigation to off-shore and on-shore remote sites, down to decision heights of 100 feet. Emphasis will be on the exploration and development of concepts that will allow helicopters to operate IFR with the same utility and flexibility that they currently have under VFR (i.e., operate independent of fixed-base landing site navigation aids). Missions to be considered include remote site operations from both a military and civil point of view. Two different techniques will be investigated, either of which may meet the civil requirement.

For the military, however, a combination of the two techniques may be required since the military requirement is to operate from remote landing sites of opportunity rather than from landing sites of known location. One navigation concept is based on the use of advanced integrated onboard sensing capability (e.g., laser gyro INS) combined with postiion-fixing using non-landing site located navaids such as the Global Positioning System. The other technique, which is a high risk approach, will apply recent advances in multi-spectral imaging and image enhancement techniques to the unique problem of helicopter IFR landing approaches. Consideration will be given to combinations of active and passive sensing techniques (e.g., weather radar and I/R video, radiometric and I/R). Most images provided by the multi-spectral sensors will be combined with vertical situation and flight director information, in order to enhance pilot useability and reduce cockpit workload.

The program phases will include analysis, simulation, systems procurement and flight test. The flight test investigations of these concepts will emphasize the following:

(a) Definition of IFR weather minimums, operational procedures, pilot performance, and certification data for various levels of system costs and complexity.

(b) Evaluation of IFR pilot performance and workload using an advanced cockpit display which combines the vertical and horizontal situation information.

(c) Minimum safe descent altitudes will be determined for various types of terrain. Visual range and obstacle detection capability of the imaging systems will be evaluated as well as the limitations of the INS-GPS navigation concepts.

(d) Definition of procedures for safe operations under expected icing conditions for remote sites such as North

Atlantic, North Sea, and Alaskan oil rigs. This activity will be closely coordinated with icing research activities which may stem from the recent Icing Workshop held at the Lewis Research Center. The rotorcraft icing technology needs were fully addressed at the workshop.

High Density 3D/4D Guidance, ATC Interfacing and Integrated Cat III Systems Technology

Key issues in civil aviation are noise, congestion, and fuel consumption. The helicopter, because of its unique operational capability has the potential of coping with the present air traffic congestion at major airports by using a minimum of airspace and by following traffic patterns which make use of airspace, separate from that used by CTOL traffic. Flight paths and operational procedures can be devised for reducing the ground perceived noise, and reducing fuel consumption. These potential improvements may be realized through the use of advanced navigation and guidance concepts, advanced airborne avionics systems and improved operational procedures. This research will be composed of a series of experiments encompassing analysis, simulation and flight test exploring system concepts, design criteria, and associated operational procedures for helicopters.

The key program elements are as follows:

(a) Investigation and development of advanced cockpit displays that combine vertical and horizontal situation information in order to reduce IFR pilot workload.

(b) Definition of ATC concepts for helicopter operations into hub airports, and city centers.

(c) Investigation and design of 3D and 4D guidance systems and complex approach paths which minimize fuel consumption, direct operating costs and noise in an ATC environment with emphasis on IFR operations.

(d) Development of advanced low-cost avionics system technology for high density 3D/4D guidance and ATC interfaces and proof-of-concept flight tests of zero-zero landings.

The results of the above described elements (a) through (c) as well as the results of the related activities, particularly the General Aviation Advanced Avionics Systems Program, and VALT Program will be used to define those avionic concepts that appear to have the greatest potential for rotorcraft and that will be pursued with a final system design, fabrication, and flight test. These program elements will be carried out in cooperative NASA-FAA simulations using facilities at ARC and NAFEC (Fig. VII-6) using simulators and flight test aircraft at ARC.

<u>Advanced Stabilization and Control Systems</u>

Figure VII-7 indicates some of the elements of concern in regard to low airspeed sensor systems on rotorcraft that will be required to achieve precision flight control at speeds from 40 knots to hover. Indicated airspeed errors are typically introduced as a function of such parameters as rotor downwash, sideward and rearward flight, flight path angle, sideslip angle, power, gross weight, and ground effect. Latest technological advances will be applied in defining system concepts to reduce the indicated airspeed errors. The results of rotor inflow studies proposed under the Aero/Acoustics Task phase of this program may make it possible to accurately measure the rotor system velocity relative to the surrounding air mass. Advanced concepts will be explored through design, fabrication and flight evaluation of bread-board systems.

Display concepts and algorithms for flight control avionic systems monitoring will be developed and tested for use in advanced, integrated systems to provide the pilot with optimum information on the failure state of the complete system and

the reconfiguration strategy being initiated by the automatics. Emphasis will be on the development and assessment of on-board avionic systems. This "self-checking" technology will be taken from the ongoing generic avionic research efforts and applied to the unique needs of rotorcraft. This work will be expanded later, under the Active Control task, to include development and validation of an integrated envelope monitoring of performance, flight control, avionic propulsion, and structures. Work on high gain systems will emphasize validation criteria and actuator technology.

Low cost SCAS systems will be developed to provide satisfactory handling qualities for civil IMC operations. Low cost will be addressed through minimizing overall system complexity and through choosing systems that require the lowest cost hardware components. Development of low cost component hardware will not be undertaken. Appropriate combinations of SCAS control laws and display concepts will be developed for several helicopters sizes with different rotor systems. The performance criteria for those systems will be generated on the basis of an extensive data base currently being compiled from the ongoing NASA/Army research program. Piloted ground-based simulation will be conducted to choose the most promising systems. The chosen systems will be implemented and evaluated on research aircraft such as the UH-1H or CH-47, taking advantage of research equipment currently installed to the fullest extent.

A summary of the All-Weather Rotorcraft program elements is given in Figure VII-8.

ACTIVE CONTROL TECHNOLOGY

PURPOSE: The purpose (Figure VII-9) of the key active control systems technology efforts is to accelerate the introduction and application of advanced digital control technology in order to provide opportunities to significantly enhance the unique mission capabilities of rotorcraft.

BENEFITS: The benefits of pursuing this work (Figure VII-9) are improvement in performance factors such as fuel efficiency, maneuverability, handling/flying/ride qualities and precision flight path control. Additional benefits are the potential reduction of control surfaces, the elimination of the vehicle empennage, and reduction of weight and complexity.

JUSTIFICATION: The use of active control technology offers opportunities for many significant performance and mission capability benefits (Figure VII-9) through improved vehicle performance; flying qualities; maneuverability; reduced weight, drag, vibration and fuel consumption. However, many active control concepts such as full authority propulsion control, fly-by-wire rotor systems, full authority aircraft flight control, high response load alleviation systems, and envelope-limiting systems require flight critical, fault tolerant designs, which in turn require validation to the satisfaction of pilots, users, and regulatory agencies.

The program approach (Figure VI-10) will emphasize analytical, simulation (including man-machine interface), and flight experiments which will accelerate the development and acceptance of these concepts through close coordination with industry users, and the FAA. Such technology development and validation is critically needed if the many significant advances offered by active control are to be realized in a timely manner.

PROGRAM: Program elements will be carried out in-house and in cooperative out-of-house efforts with manufacturers, users, and the FAA. Systems architecture will be developed and validated. Validation criteria will be formulated and verified to establish the correct balance between analytical, simulation and flight methods. The two main task areas are full authority systems, which will address the technology of flight critical control systems, and mission capability improvement to provide improved response for safe, low-altitude missions, and systems for handling external loads with reduced pilot workload.

Full Authority Systems Technology

Full authority systems technology will emphasize the design, evaluation and validation of flight critical, full authority systems concepts typically associated with fly-by-wire, fly-by-light and control configured vehicle technology.

Methods for assessing failure modes and degraded mode performance such as introduction of failures without violating systems integrity and methods of interpreting the results, etc., will also be emphasized in the early stages and will be built on industry, NASA and FAA experience that is being obtained through on-going programs.

Pilot vehicle interface, workload, and interpretation accuracy, pilot roles in the validation process, and pilot techniques for improved degraded mode safety will be investigated.

An integrated flight-critical control system will be jointly defined with industry (Figure VII-11), with the end goal of flight testing a fault-tolerant full authority flight control system. This system will be designed to have low initial cost, low maintenance costs, and high reliability. Hardware and software will be built according to the fault tolerant design described above. A variety of tools will be used to aid in the design, development, simulation, validation, and

test of this system. These tools, some of which need to be developed, include: programs to aid in system software specification, development and validation, and to develop and check redundancy management and reconfiguration logic; an emulator to test software prior to hardware availability; and a ground test system for final software and hardware validation; both on a hot bench and in the helicopter. Real time piloted simulations will be performed to check the overall system and the pilot-vehicle interface. These simulations will include the determination of the complete system performance, as well as the performance in a variety of degraded modes. The failure mode logic will be evaluated, along with any failure transients. The system will then be installed in a representative helicopter, and evaluated in flight.

MISSION CAPABILITY IMPROVEMENT

Fast Response, Precise, Low Altitude Guid, Nav, and Control

Primary emphasis will be placed on the design and validation of a "local area" (5 NM to 75 NM) high precision, low altitude, fast response navigation and guidance system (Figure VII-12), and an associated wire and obstacle detection and warning system. The objective is to provide improved response (time enroute reduced by 20%) for safe low altitude (50' to 500' above the terrain) missions having local area addressing (navigation) resolution in the order of $\pm$ 10' to 100' in the horizontal directions.

The primary operational mode to be developed will be one which provides the pilot with navigation and guidance information for rapidly responding and precisely locating a new destination, i.e., address under visual flight conditions. The large data storage capacity of current technology computer memories will serve as a means for storing large amounts of information regarding a specific local area in a manner that can be displayed to the pilot in an operationally acceptable manner.

These low altitude fast response missions require improved protection against flight path obstructions and in particular, wire strikes. Civil and military technology advances will be utilized in defining, developing, and constructing a wire and obstacle detection and warning system. The goal is to reduce by 60% the current civil helicopter wire strike accident rate of 2.6 wire strike accidents per 100,000 flight hours.

Systems concepts will be defined in cooperation with public service organizations (police, fire, rescue), the military, user organizations (logging, lumbering, construction) and community/state agencies. An advanced, low-cost system will be constructed and validated in simulation and flight to determine its performance and to accelerate the opportunities for applying advanced systems technology in unique public service, utility and military missions.

Research by the Army in support of Nap-of-the-Earth (NOE) mission requirements is closely related to work described in this New Start due to mission similarity. The NOE mission requires low altitude, 3-D navigation capability in a specific local area of hostile environment with natural and man-made hazards. Time to identify and correlate check points with maps is at a minimum, and navigation accuracy for joint air-ground operations is at a premium due to limited inter-visibility. The Army plan is to provide current Army navigation systems with a 3-D capability through an evolutionary building block process rather than developing a totally new system. Low-cost, light-weight sensor/processor/display modular blocks using new magnetic; radiation, and nav-computer technology will be used to fit the basic architecture of current navigation systems. The Army has developed and flight tested a Laser Obstacle/Terrain Avoidance Warning System (LOTAWS) as part of a Multifunction Environment Sensor Program. LOTAWS has demonstrated in flight tests the detection of 1/8-inch wire at ranges of 1500 ft with a secondary capability for

terrain following. These military technologies will be utilized in system concepts described in this program.

High Precision External Load Control

Suspension and stabilization systems for the handling of external loads will be developed to expand usable flight envelope and to achieve a satisfactory level of pilot work-load. These systems will be integrated with the helicopter flight control systems. The concepts to be implemented will be chosen on the basis of research conducted under the on-going NASA/Army program. Both single rotor and tandem rotor helicopter configurations will be considered. Systems chosen for study will be implemented on research aircraft such as the CH-47B. Goals, which are of interest for both civil and military operations, include stabilization of loads at high forward speeds, precision placement of loads under adverse weather conditions, and detection/dissipation of static electricity.

The time-phased summary of the Active Control program tasks are shown in Figure VII-13.

FLIGHT CONTROL AND AVIONIC SYSTEMS

OVERALL OBJECTIVE:

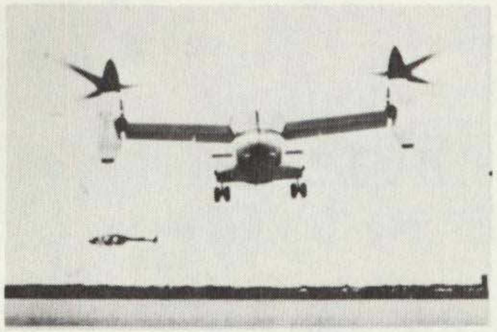
APPLY BROAD BASED GENERIC AND VEHICLE SPECIFIC CONTROL AND AVIONICS TECHNOLOGY TO SIGNIFICANTLY ENHANCE THE UNIQUE OPERATING CAPABILITIES OF ADVANCED ROTORCRAFT

AREAS OF EMPHASIS:

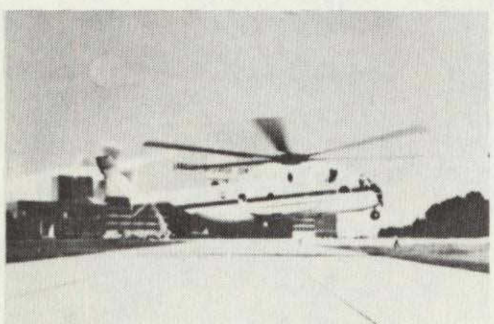
ALL-WEATHER ROTORCRAFT OPERATION
ACTIVE CONTROL TECHNOLOGY

FIGURE VII-1

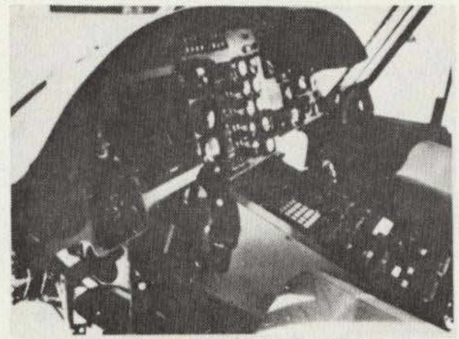
ROTORCRAFT OPERATING SYSTEMS
FLIGHT EXPERIMENTS



XV-15 TILT ROTOR



NCH-53A



ADVANCED DIGITAL
AVIONICS SYSTEMS

AIRBORNE RADAR

CH-47

SH-3

UH-IH

FIGURE VII-2

ALL-WEATHER ROTORCRAFT

PURPOSE:

TO PROVIDE THE CRITICAL TECHNOLOGY TO ALLOW INSTRUMENT METEOROLOGICAL CONDITION (IMC) ROTORCRAFT OPERATING PERFORMANCE COMPARABLE TO PERFORMANCE UNDER VISUAL METEOROLOGICAL CONDITIONS (VMC)

GOALS/BENEFITS:

IMC OPERATIONS DOWN TO 100 FT. DECISION HEIGHTS USING ON-BOARD SYSTEMS FOR REMOTE SITES

IMC OPERATIONS DOWN TO 50 FT. DECISION HEIGHTS FOR HIGH DENSITY TERMINAL AREAS.

FIGURE VII-3

ALL-WEATHER ROTORCRAFT

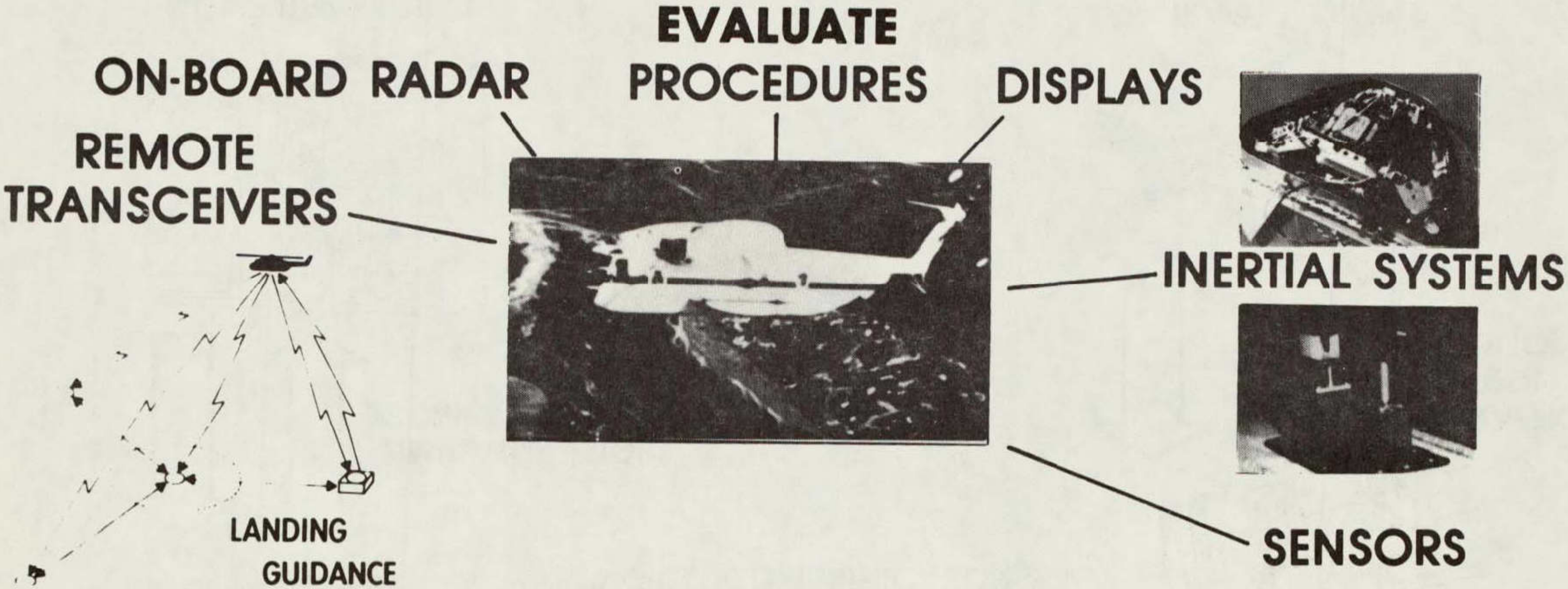
APPROACH:

REMOTE SITES - DEVELOP ADVANCED TECHNOLOGY FOR ON-BOARD GUIDANCE AND NAVIGATION BASED ON OPERATING DATA OBTAINED IN COOPERATION WITH USERS, INDUSTRY AND FAA

HIGH DENSITY TERMINAL AREAS - EVALUATE AND INTEGRATE ADVANCED 3D/4D TECHNOLOGY WITH THE AIR TRAFFIC CONTROL SYSTEM THROUGH DIRECT VEHICLE SIMULATION INTERFACE WITH FAA ATC SIMULATION CAPABILITY

FIGURE VII-4

REMOTE SITE GUIDANCE AND NAVIGATION
DESIGN AND OPERATING CRITERIA



RELATED TASKS

- ADVANCED STABILITY AND CONTROL AUGMENTATION SYSTEMS
- ICING TECHNOLOGY
- LOW AIRSPEED SYSTEMS
- PRECISION LOW ALTITUDE GUIDANCE AND NAVIGATION

FIGURE VII-5

ROTORCRAFT AIR TRAFFIC CONTROL SIMULATION

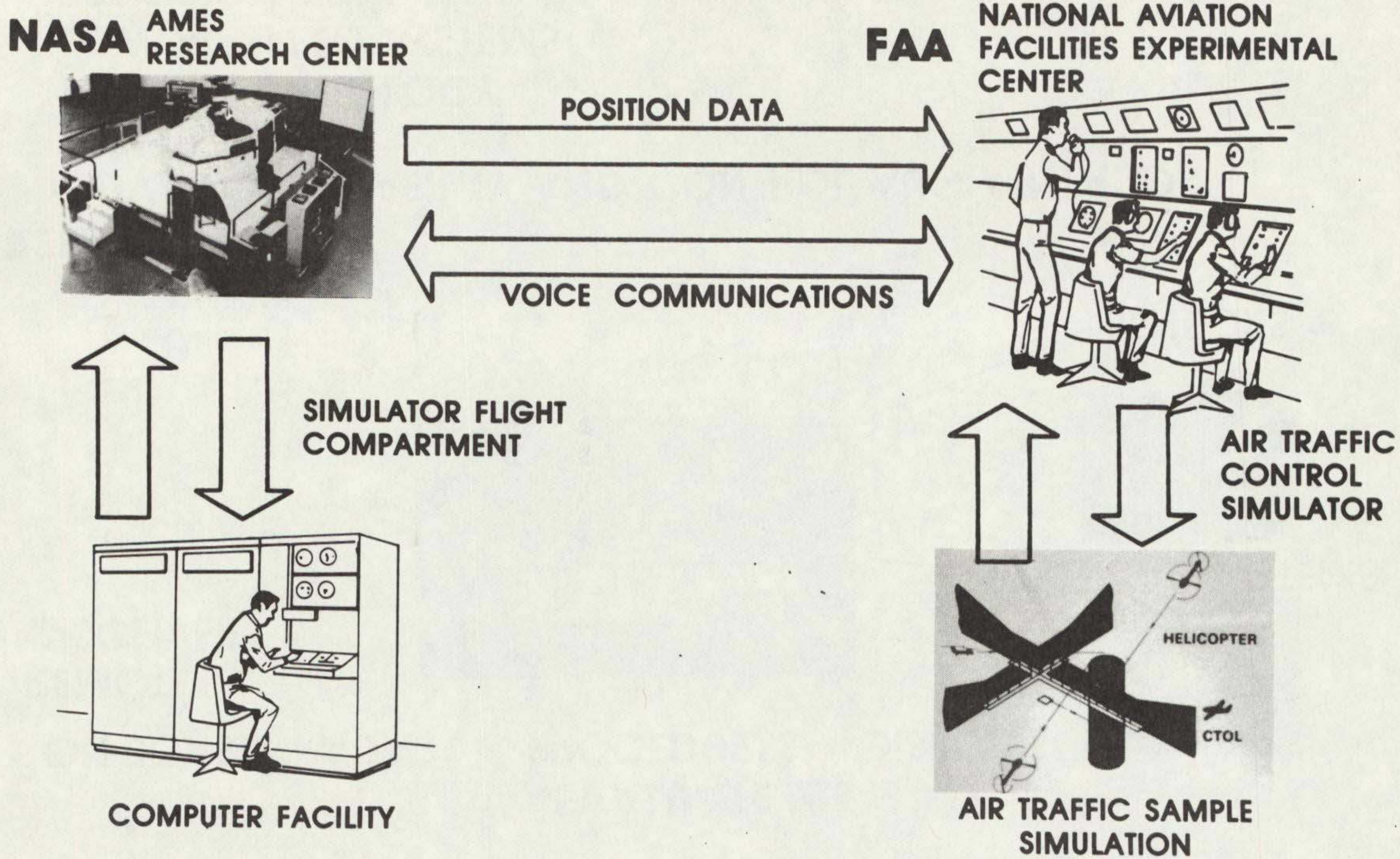
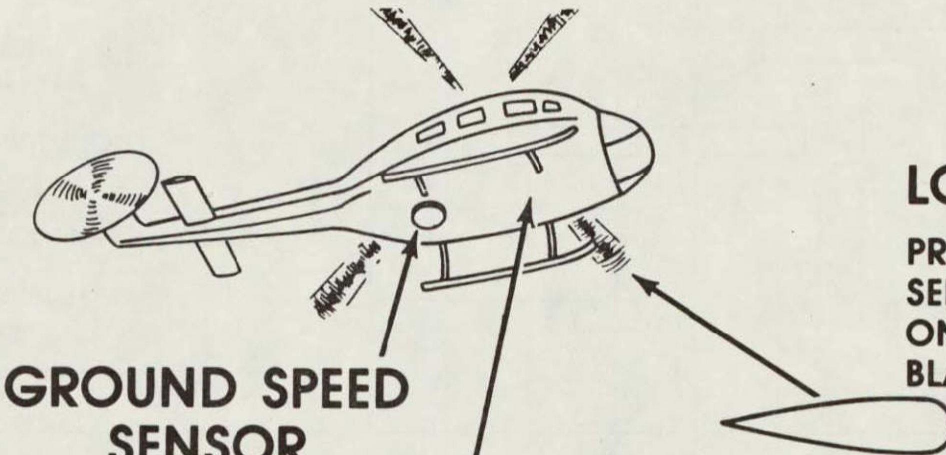


FIGURE VII-6

LOW SPEED SENSOR SYSTEMS
0 TO 40 KNOTS

PRECISION HOVER TASK

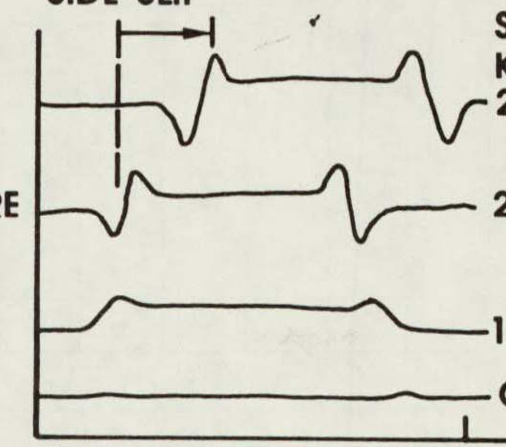


GROUND SPEED SENSOR

DISPLAYS
MICROPROCESSORS
INERTIAL SENSORS

LOW AIRSPEED

PRESSURE SENSORS ON OUTBOARD BLADE SECTION



NOTE:
Rotor Low Airspeed System Task Interfaces With Aero/Acoustic Tasks

FIGURE VII-7

ALL WEATHER ROTORCRAFT

SUMMARY

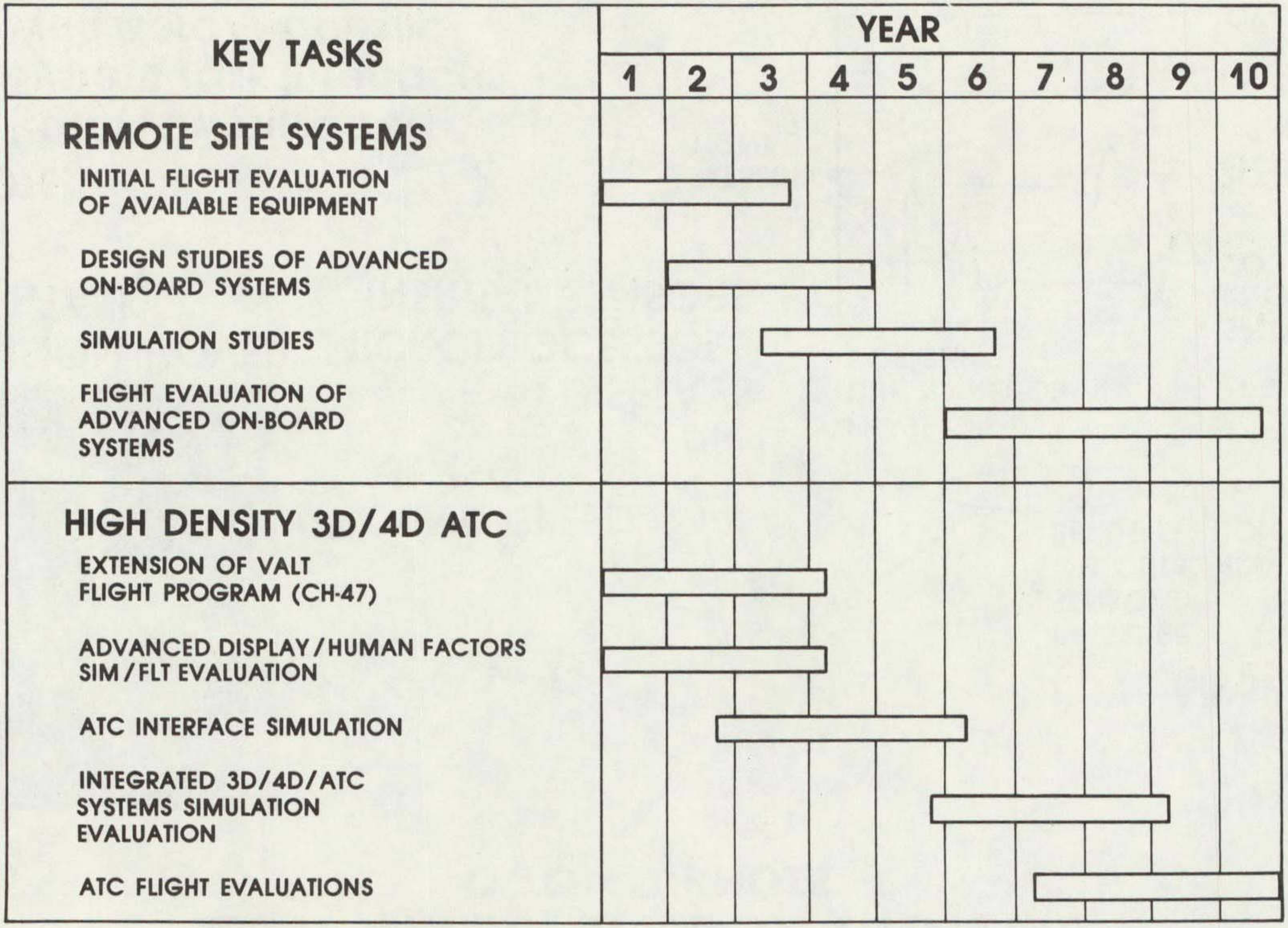


FIGURE VII-8

ALL WEATHER ROTORCRAFT
SUMMARY

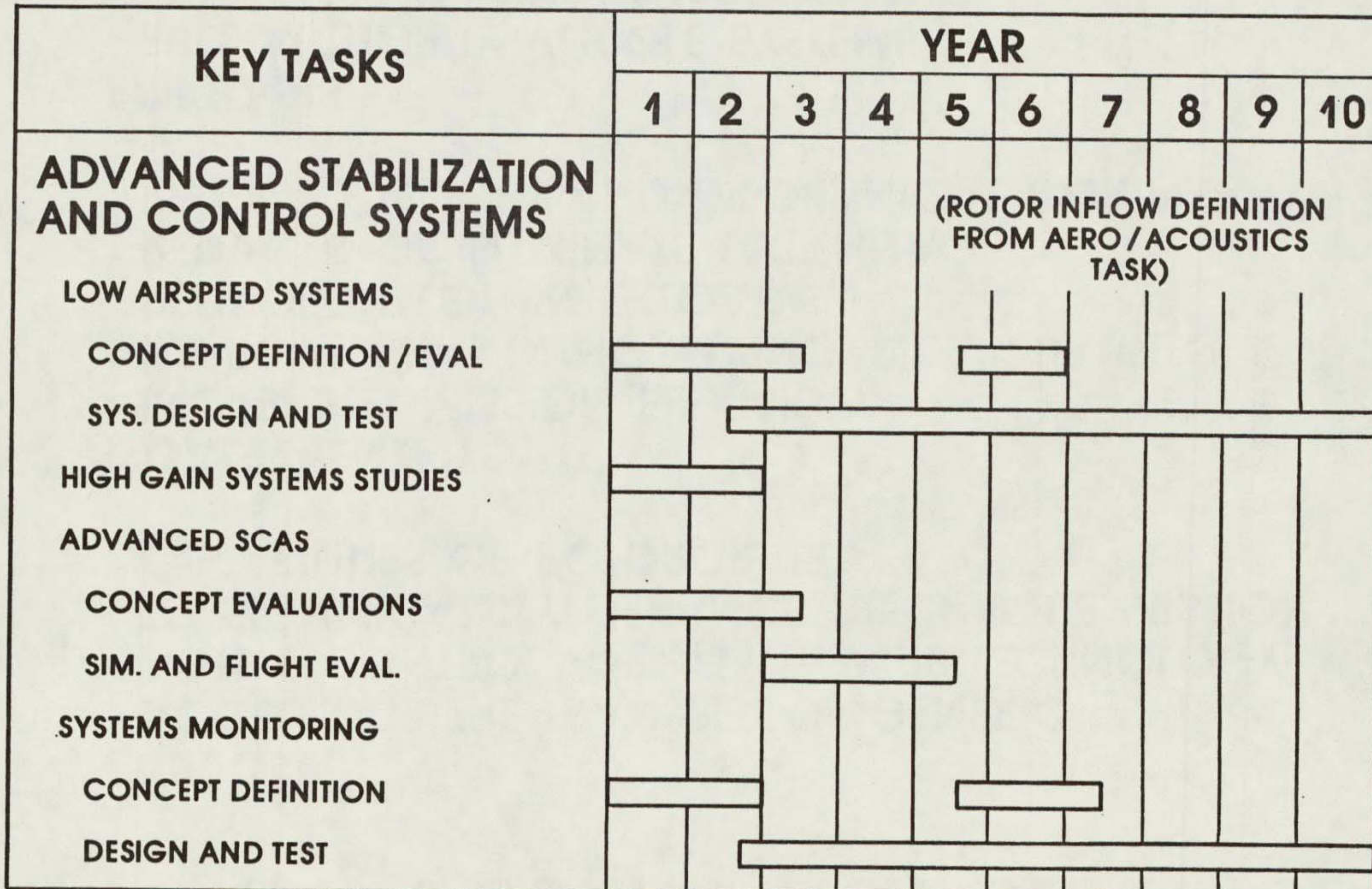


FIGURE VII-8 (CONCLUDED)

ACTIVE CONTOL TECHNOLOGY

PURPOSE:

ACCELERATE THE TRANSFER OF GENERIC
ACTIVE CONTROL AND FLY-BY-WIRE TECHNOLOGY
TO SIGNIFICANTLY ENHANCE THE UNIQUE MISSION
CAPABILITIES OF ROTORCRAFT

GOALS/BENEFITS

INCREASED MISSION FLEXIBILITY
IMPROVED HANDLING/FLYING/RIDE QUALITIES
REDUCED PILOT WORKLOAD
REDUCED OR ELIMINATE EMPENNAGE
REDUCED WEIGHT AND MECHANICAL COMPLEXITY

EMPHASIS:

FULL AUTHORITY VEHICLE SYSTEMS
MISSION CAPABILITY IMPROVEMENT

FIGURE VII-9

ACTIVE CONTROL TECHNOLOGY

APPROACH:

FOCUS ON THE UNIQUE ASPECTS OF THE FOLLOWING TECHNOLOGY AREAS AS THEY APPLY TO ADVANCED ROTORCRAFT

- SENSOR/ACTUATOR SYSTEMS
- FLY-BY-WIRE SYSTEMS
- CONTROL CONFIGURED CONCEPTS
- VIBRATION REDUCTION (SEE DESIGN METHODOLOGY TASK)
- INTEGRATION OF ROTOR/AIRFRAME/PROPULSION CONTROL AND MONITORING SYSTEMS
- ADVANCED STABILITY AND CONTROL AUGMENTATION SYSTEMS

FIGURE VII-10

ACTIVE CONTROL TECHNOLOGY
FULL AUTHORITY SYSTEMS TECHNOLOGY

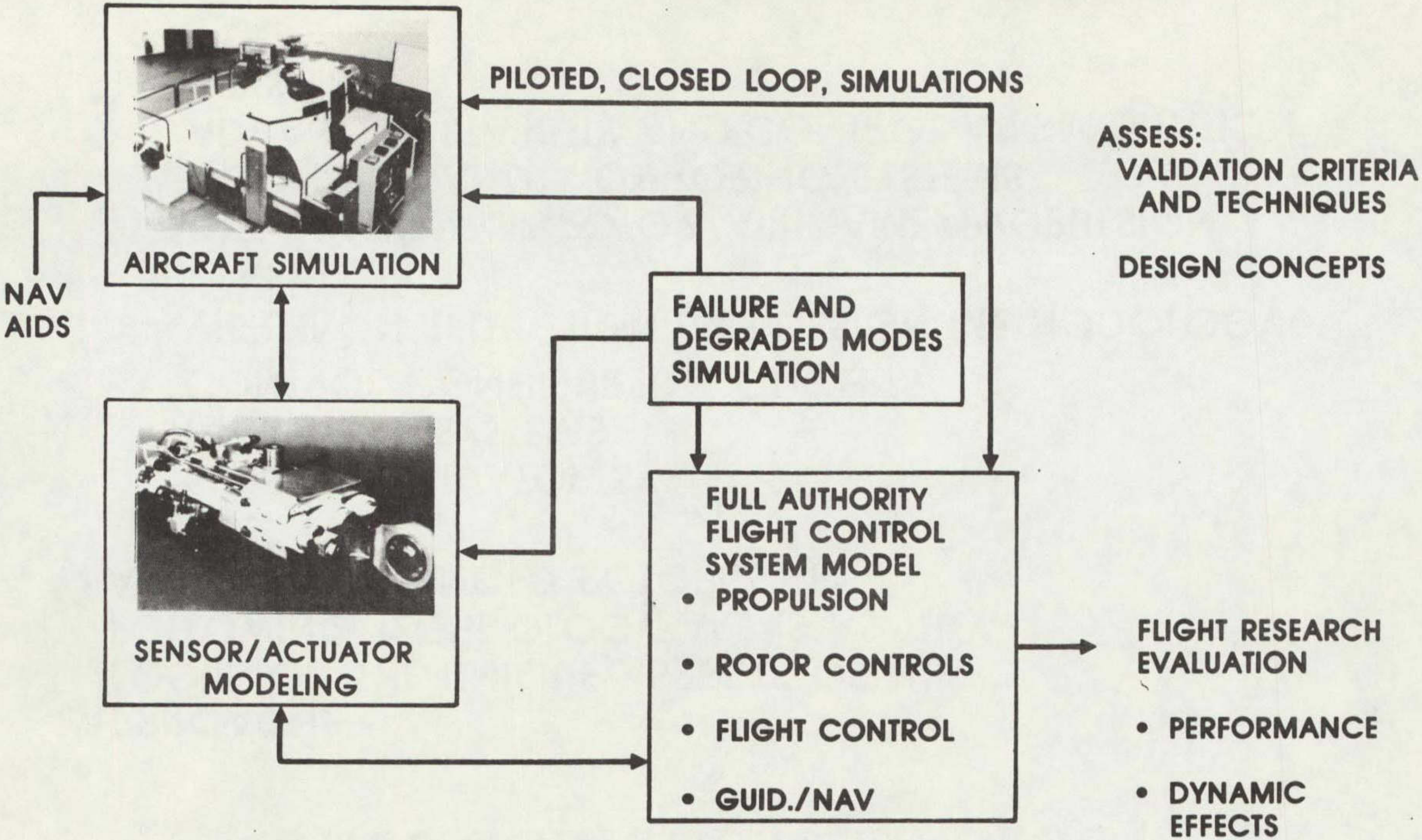
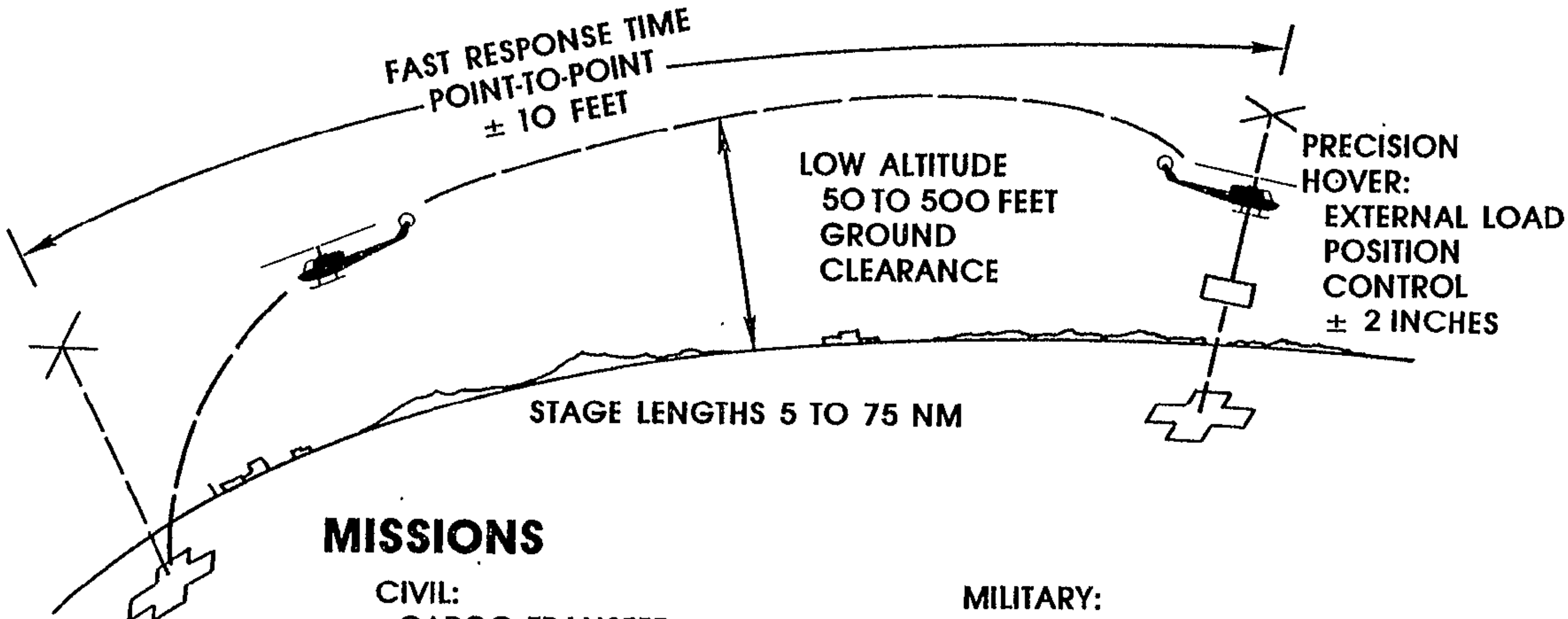


FIGURE VII-11

IMPROVED MISSION CAPABILITY
HIGH PRECISION



MISSIONS

CIVIL:
- CARGO TRANSFER
- LOGGING
- CONSTRUCTION
- RESCUE
- POLICE (QUICK RESPONSE)
- AMBULANCE (QUICK RESPONSE)
- FIRE (QUICK RESPONSE)

MILITARY:
- SHIP-TO-SHIP
- NAP-OF-THE-EARTH
- ASW
- CARGO TRANSFER

FIGURE VII-12

ACTIVE CONTROL
SUMMARY

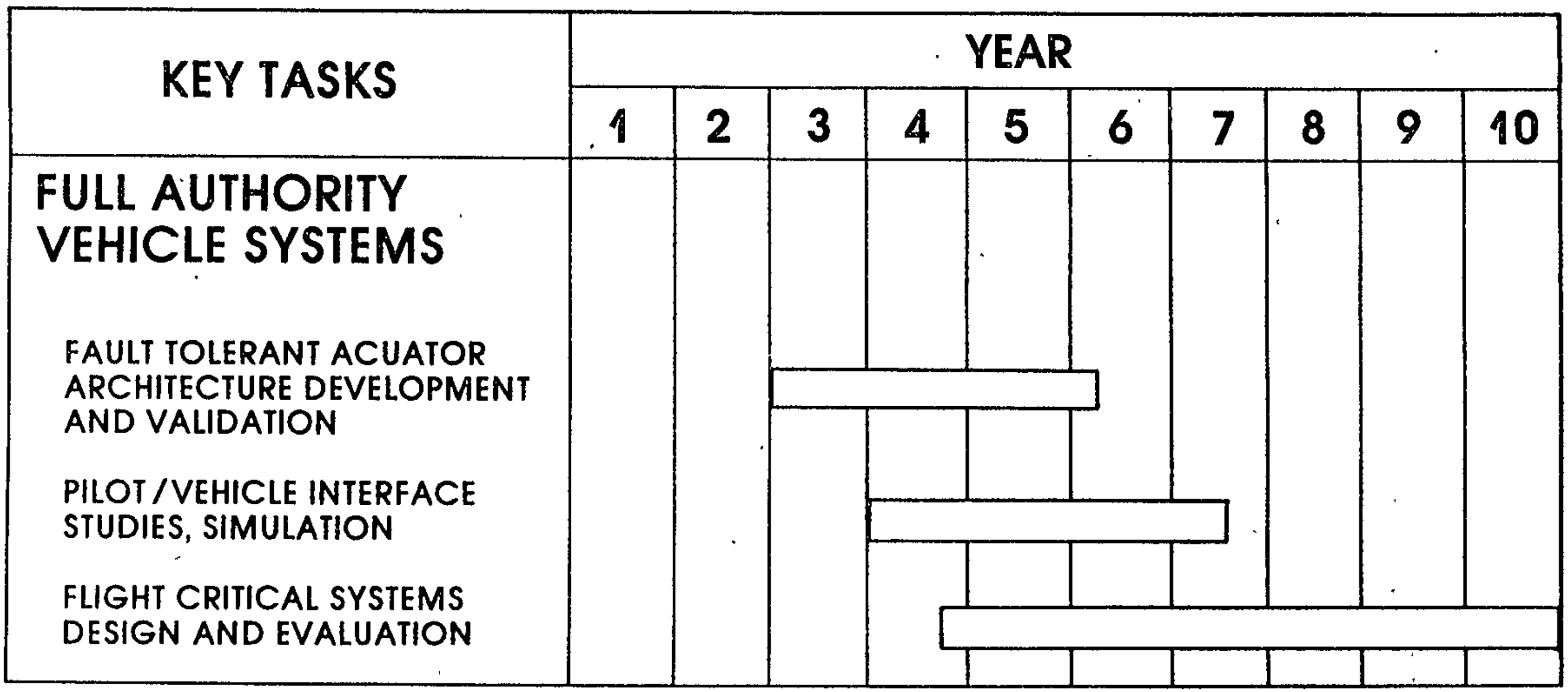


FIGURE VII-13

ACTIVE CONTROL

SUMMARY

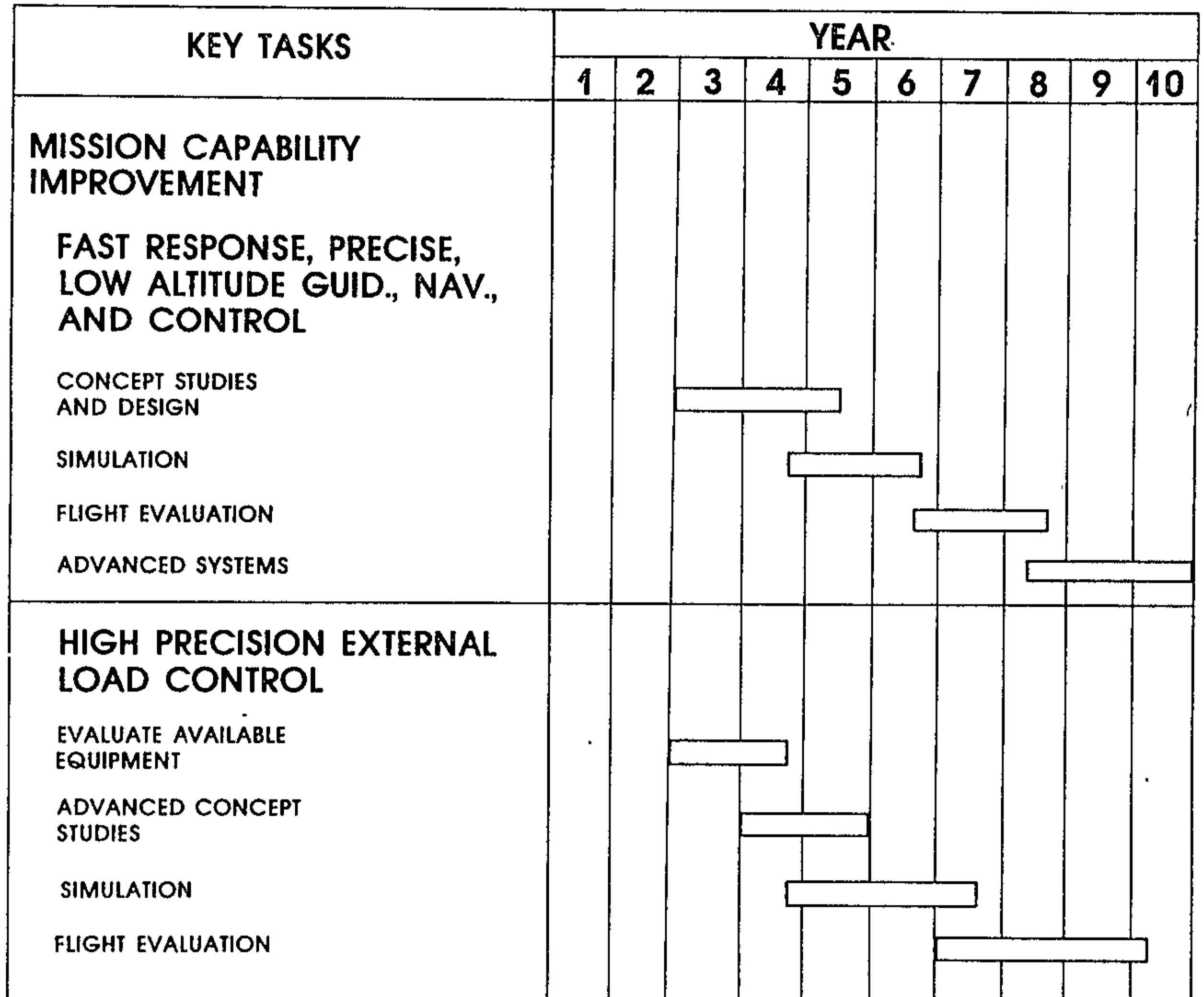


FIGURE VII-13 (CONCLUDED)

PROPULSION

The overall purpose of the propulsion program is to develop analytical design tools and advanced propulsion concepts for future rotorcraft. The main objectives of the program (Figure VIII-1) are to (1) improve engine and power transfer component reliability and maintainability, (2) reduce engine fuel consumption over the full range of operation, (3) improve environmental acceptability and (4) reduce the cost of acquisition and operation. These objectives will be pursued by executing the program elements shown on Figure VIII-2. As indicated, the program elements are time phased through the ten year time period. The phasing was established to initiate the highest priority program elements, e.g component design methodology, in the early years. Each of these program elements will be described in more detail subsequently.

The program elements were selected to be responsive to the needs described by the rotorcraft manufacturing community and the users, both civil and military. One of the key issues that was brought forth was the need to improve the durability and maintenance characteristics (Figure VIII-3) of rotorcraft engines. Considerable progress has been achieved in the fixed wing turbine engines through the employment of advanced technologies to improve hot section durability and life. The task of making similar progress in rotorcraft engines will be difficult because of the hostile environment and cyclic operational requirements imposed on them. Additionally, performance improvements in small gas turbine engine components are more difficult to achieve due to the factors listed in Figure VIII-4. Because of the small physical size of the engines, component technologies developed for the larger fixed wing class of turbine engines is not applicable. The use of centrifugal flow components and low aspect ratio blading represents a different class of technology than is currently being developed for the large engines. Furthermore, adverse size effects are encountered in small turbomachinery which prevent the ability to "scale-down" the performance characteristics of the larger technologies.

The foregoing factors represent only a small fraction of the total problems that are related to propulsion systems for rotorcraft. Other considerations such as

the durability, maintainability, noise and vibration of transmissions, the complexity of controls, and the compatibility of inlets and engines were also important factors used in developing the propulsion program plan.

ENGINE COMPONENT DESIGN AND METHODOLOGY

PURPOSE:

- Improve the life, reliability, maintainability and efficiency of future small gas turbine engine components.
- Reduce the design and fabrication costs and improve environmental tolerance of future small gas turbine engines. The achievement of the component design methodology objectives will be sought by exploring the six key technology task areas shown on Figure VIII-5.

BENEFITS: The key benefits that will be derived from this program element are related to reducing the cost of acquisition and operation of rotorcraft by reducing engine development time and improving engine performance, reliability and maintainability.

JUSTIFICATION: Current analytical design techniques are not adequate for accurately predicting the performance characteristics of small turbine engine components. The lack of computational techniques and an empirical data base for small complex, high pressure ratio axial/centrifugal flow compressor stages (Figure VIII-6), axial/radial flow turbines and axial/reverse flow combustors has caused new engine development times to be inordinately long (up to 10 years). The inability to accurately predict the matching characteristics of multiple compressor stages has led to stall margin problems that require considerable development time to solve. The inability to accurately design effectively cooled turbine components has led to aerodynamic and hot section life penalties. Similar problems exist in the current design approaches for combustors. The advantages of going to full authority electronic digital control (FADEC) is well documented but the effective use of this control technique for helicopter engines will require the development of appropriate electronic components. Analytical simulation techniques to determine optimum

control modes and empirical design data on electronic components, fiber optics and miniaturized sensors are not available for small gas turbine engines especially those applicable to rotorcraft.

One area where knowledge is sorely lacking is in the ability to understand the impact of environmental operational considerations on engine component life and performance. Rotorcraft, many times, operate in very hostile environments such as salt spray and blowing sand and dust. In consideration of these factors, engine components are either overdesigned or require constant cleaning while in service. Furthermore, erosion and corrosion occur at a rate that is not predictable. Information is needed on in-service engines to evaluate these factors and thus provide the knowledge needed to design environmentally tolerant high-performance rotorcraft engines.

PROGRAM:

The key technology task areas in engine component design methodology are as follows:

1) Analytical Design Techniques.- Analytical design techniques will be established using both computational and experimental methods (Figure VIII-7). These techniques will be continuously modified to more closely represent actual flow conditions by incorporating the results of experiments conducted in the compressor, turbine, combustor, task areas. Techniques will be established to calculate and analyze flow conditions in bladed passages and design criteria will be developed to incorporate related considerations for durability, reliability, and cost of turbomachinery components. Analytical models for predicting turbine blade and vane heat transfer, combustion aero-thermodynamics and fuel atomization, and electronic control system response characteristics will also be developed and verified.

2) Axial/Centrifugal Flow Compressors.- Parametric experiments will be conducted to develop a strong empirical data base for single stage axial and centrifugal compressor stages. Two flow sizes will be selected for experimental study (1-2 lbs/sec and 9-10 lbs/sec). The data base will be used to optimize the analytical design techniques for small size hardware and as the basis for selecting appropriate axial/centrifugal or centrifugal/centrifugal staging arrangements. Based on empirical data from multistage compressors, stage matching criteria will be evolved and verified over the entire range of operation from full to part speed. Data feedback to the analytical design technique task area will be continuous.

3) Axial/Radial Flow Turbines.- Effects of unsteady flow and turbulence on vane and blade heat transfer will be studied. Rigorous 3D viscous flow computer codes will be modified to include heat transfer and coolant addition by applications of empirical data. These results will be incorporated into the analytical design techniques task area. Effects of geometrical factors, such as tip clearance, aspect ratio and end-wall contour, will be experimentally evaluated to establish a strong empirical data base. This data base in concert with analytical design techniques will be used to design and evaluate conceptual high temperature axial and radial turbine stages. Two flow sizes (same as the compressors) will be evaluated. Data feedback to the analytical design technique task area will be continuous.

4) Axial/Reverse Flow Combustors.- A study will be conducted to establish the critical design criteria of small gas turbine engine combustors. Design parameters will be categorized in terms of potential for achieving high performance, low emissions, and reliability and durability. Experiments will be conducted to establish

empirical correlations of the key design parameters and conceptual combustor designs will be generated. A data base relating to primary zone design, liner wall cooling and dilution jet mixing will be generated. Two flow ranges (same as compressors) will be evaluated. Data feedback to the analytical design technique task area will be continuous.

5) Electronic Controls.- Full authority digital electronic control (FADEC) components will be evaluated in terms of high reliability and low cost. Digital-compatible sensors, effectors and fiber optic signal transmission lines will be evaluated as individual components and as a complete system. Digital and analog/digital hybrid computers will be used to simulate control system performance and to optimize component design parameters for a variety of control modes. Data feedback to the analytical design techniques task area will be continuous.

6) Diagnostics.- Maintenance records of rotorcraft users and engine manufacturers will be evaluated to identify the most prevalent causes of failure or reasons for removal of rotorcraft engines. Selected rotorcraft engines will be "tracked" during actual in-service operation to monitor and document the time/life history of their components. A comprehensive data base will thus be established to identify and document key factors (environmental and operational) which can be used to establish acceptable reliability and maintainability criteria. Based on these results, advanced technology sensors will be developed for subsequent use system condition monitoring studies. Analytical models of time/life history will be developed by continuous data feedback to the analytical design techniques task area.

The six key technology tasks will be time phased as shown in Figure VIII-8.

POWER TRANSFER TECHNOLOGY

PURPOSE:

- Improve the life, reliability and maintainability of future rotorcraft transmissions and other power transfer components.
- Reduce the size, weight, noise, and vibration, and the design and fabrication costs.

The achievement of the power transfer technology objectives will be sought by exploring the four key technology task areas shown on Figure VIII-9.

BENEFITS:

The key benefits that will be derived from this program element are related to reducing the cost of acquisition and operation of rotorcraft by reducing transmission and drive train development time, simplifying, compacting and lightening the transmission (Figure VIII-10) through the application of traction drive concepts (Figure VIII-11) and other advances stemming from the R&T Base efforts; and greatly improving the reliability and maintainability. Also, passenger acceptance will be enhanced, pilot fatigue reduced, and component life extended due to the lower noise and vibration levels.

JUSTIFICATION:

Current helicopters are penalized with high operating costs due in part to the high maintenance rate of the transmission components (Figure VIII-12). As a result, the transmission reliability for long-life application is relatively low. Thus, the time between overhaul and mean time between failure on present day helicopters are much lower than that required for many commercial operations. The helicopter drive system is generally heavier than desired. In general, current state-of-the-art transmission systems are disturbingly noisy to the pilot and passengers. As shown in Figure VIII-13, the noise problem is more severe as the rotorcraft power consumption increases. Also, the current transmissions are generally lighter than those used in the past and this is believed to result in a noisier transmission for the same power capacity of previous designs. The identification of noise and vibration sources and the

efficient means of reduction are not well understood. As in small gas turbine engines, knowledge is lacking in the ability to understand the impact of operating environment and conditions on power transfer component life and performance. Information is needed on in-service transmissions and drive trains to evaluate these factors and hence provide knowledge needed to design long life power transfer components.

The objectives can be met in part with higher speed, higher operating temperature, lightweight mechanical components with improved lubrication. Costs may be reduced with simpler, compact, more forgiving power transfer system designs than the current design practice. Clutches and couplings for rotorcraft have received little attention and thus potential benefits are great from a research program on these components.

Traditionally, power systems analysis capability is very limited and based on past experience. Hence, improved practical computational techniques are needed for the relatively highly-loaded, lightweight transmission and drive train components that are operating under highly variable loads, and high vibratory and transient conditions.

PROGRAM: The four key technology task areas will be time phased as shown on Figure VIII-14.

1) Noise and Vibrations.- The major task emphasis will be on obtaining a fundamental understanding of sources, analytical prediction techniques and design concepts for noise and vibration reduction. Experimental methods will be developed for identifying the sources, such as structural deformations, contributing to noise. Improved analytical methods will be developed to predict the noise and

vibration. Source noise and vibration will be reduced by investigating new gear tooth designs, alternative gear arrangements, and low noise and vibration transmission concepts. Advanced materials, characterized by high structural efficiency and damping, will be applied to both the power transfer components and housings.

2) Diagnostics.- Maintenance records of rotorcraft users and airframe manufacturers will be evaluated to identify the high maintenance action components and failure causes of the transmission and drive train. Selected rotocraft power transfer systems will be "tracked" during in-service operation to record the time/life history of the components. A comprehensive data base will be established that will identify critical operating and environmental factors that influence reliability and maintainability.. These results will be used on both the advanced components and concepts work. These results will also be used to develop sensors and displays that will subsequently be used in system condition monitoring studies. Analytical models of time/life history will be formulated and used in establishing practical computational techniques for power transfer components and systems.

3) Advanced Components and Design Criteria.- Mechanical components such as gears, bearings, seals and shafts will be designed and developed to operate beyond current state-of-the-art speeds, to be lighter in weight, to be capable of higher temperature operation and to be more "forgiving" to rotorcraft operating environments. Particular emphasis will be placed on tapered roller bearings, high-speed clutches and couplings, and improved lubrication techniques. Flexible power transmission shafting, which is simpler and lighter in weight than rigid shafting, will also be addressed by developing the proper analytical tools so these shafts

can be practically used. Life and reliability data on new materials, and mechanical component designs will be established. Analytical life analysis for transmission systems and components will be developed. Bench studies and full-scale component fatigue tests and operation simulation tests will be conducted. The data base and predictive tools will also be used in advanced transmission system component designs as they are developed.

4) Advanced Concepts.- The major task emphasis will be on identifying, developing, and "proof of concept" demonstrating advanced power transfer systems.

Promising new transmission concepts and designs will be screened by analysis. Sub-scale models of the best candidates will be designed, fabricated and parametrically tested. Full-scale transmission fabrication and testing will follow. Concepts to be investigated include advanced traction and hybrid drives (Figure VIII-10) characterized by high reduction ratios and equal load sharing. Other concepts to be examined will include torque splitting, free planet, and variable speed drives. This task will use input from the noise and vibration, diagnostics, advanced components, and the integrated engine/controls/power transfer systems integration tasks to achieve the power transfer system goals. Particular emphasis will be placed on an integrated transmission, rotor control and rotor system design approach resulting in a simpler and more compact system.

SYSTEMS INTEGRATION

I. PROPULSION CONTROL

PURPOSE:

- To improve the reliability, maintainability, stability and safety of future rotorcraft propulsion systems.
- To improve the installed performance of fully integrated propulsion/control systems over the entire range of vehicle operation.

The achievement of the systems technology objectives will be sought by exploring the key technology task areas shown on Figure VIII-15.

BENEFITS:

The principal benefits that will accrue from successfully exploring the systems technology key technology task areas will be associated with increased propulsion system safety, reduced maintenance costs and increased propulsion system options for future rotorcraft engines. For example, studies have shown that an effective emergency power system could reduce power mishaps by over 50 percent and increase commercial payloads up to 250 percent.

JUSTIFICATION:

Premature, and many times unnecessary, removals of propulsion system components, e.g., engines or transmission, result in economic penalties to rotorcraft users. The inability to accurately and reliably monitor and/or predict the condition of propulsion system components is generally the cause of these removals. The development of reliable sensors and display/record systems along with accurate analytical models for predicting time/life histories will minimize these early removals and thus optimize the installed, useful service of propulsion systems. Total system experience is needed to verify condition monitoring systems under actual and varied field service applications.

Emergency power in rotorcraft engines is needed to provide pilots with adequate power when one engine of a multi-engine installation becomes inoperative. Minimization of forced

and crash landings could be avoided and improved payload capability would be provided, due to optimizing engine normal maximum power needs. Emergency power is normally needed at the most critical flight conditions, takeoff and landing. Techniques that are efficient, simple to operate and light weight are needed to provide economical and reliable systems.

Operation of rotorcraft in all weather conditions can result in icing conditions at the engine inlet. Furthermore, operating in adverse environmental conditions, such as sand and dust, and during low level transition to hover can cause distorted flows to occur in the engine inlet. These conditions cause losses in the stall margin of the engine compressor and can result in marginal and sometimes unsafe operation. Inlet systems which can minimize these effects and compressors which are more stall tolerant will be needed. The ability to analytically describe these cause/effect relationships is not in hand. An augmented effort to expand a current program on determining the stall tolerance of an existing rotorcraft engine (Figure VIII-16) to distortion is needed to provide the experimental data base needed to develop analytical models.

Electronic digital controls can provide large improvements over conventional hydromechanical control systems in terms of simplicity, cost, reliability and ease of operation (Figure VIII-17). Electronic control components, such as sensors and signal transmission lines, cannot be fully evaluated in component tests. Time response characteristics of total propulsion systems, i.e., engines, controls and power transfer mechanisms, must be evaluated in a totally integrated mode. These evaluations must be conducted in systems which simulate as closely as possible that actual environment that will be encountered in

in-service applications in order to develop realistic analytical simulations and to provide confidence in reliability and efficiency.

Exploring the full potential of future rotorcraft may require propulsion systems with more flexible and more efficient performance than current gas turbine engines. The ability to provide efficient very small turbine engines, e.g., <300 SHP will likely require engine cycles using hot gas recuperators and/or variable geometry. These cycles can also improve the part power SFC losses, (Figure VIII-18) that occur in conventional cycles. Transferring power from the rotor to a propellor or fan (compound engine) will also require modifications to conventional gas turbine cycles. Intensive studies into these and other innovative cycles, such as rotor tip drive systems are needed to provide propulsion choices for future rotorcraft.

PROGRAM: The time phasing of the key technology task areas is shown in Figure VIII-19.

1) System Condition Monitoring.- Advanced technology sensors for detecting such internal factors as gas, metal and lubricating oil temperatures will be installed in key locations throughout in-service propulsion systems. These sensors will be mated to advanced data transmission techniques, such as fiber optics (Figure VIII-17), and advance data acquisition, storage and display systems. In-service time history data will be accumulated from a variety of rotorcraft vehicle and mission types. These data will be used to develop analytical models for predicting the life history of critical propulsion sytem components (engines and power transfer mechanisms). Also proof-of-concept for "real time" condition monitoring systems will be

evaluated for their ability to predict component removal needs. The resultant analytical models will be used to guide the direction of research and development on advanced propulsion components for future rotorcraft.

2) Emergency Power/Structural Integrity.- Various methods of augmenting engine power will be analytically evaluated. Several candidate techniques such as running the engine at higher speeds and/or turbine inlet temperatures for short periods of time and injecting a liquid to increase the mass flow while maintaining speed and temperature will be evaluated. Other innovative techniques will also be sought for both engine and system application. Attractive techniques will be experimentally explored to evaluate technological capabilities. The effect of incorporating emergency power techniques on the structural integrity of engine components will be evaluated and attractive techniques will be evaluated in terms of their effectiveness and practicability of application.

3) System Integration.- A complete engine/electronic control/transmission system will be assembled and experimentally evaluated in a ground test facility. Simulated rotor power loads will be used to document the effectiveness of electronic control components and sensors to meet both the steady state and transient performance requirements of the total system. These data will be used to develop analytical simulation techniques for predicting the performance potential of full authority digital electronic controls (FADEC) for rotorcraft applications. Ground test experience will also be used to "ferret-out" potential problems of FADEC systems as applied to rotorcraft.

Improved engine inlet and separator aerodynamics and ice protection designs will be evaluated in scale model tests.

Improved instrumentation and ice protection technology will be evaluated in accurately simulated icing conditions and the resulting data will be used to develop improved analytical tools for predicting and modeling ice build-ups on rotorcraft engine inlet systems. Simulated pressure and temperature distortions will be imposed at the inlet of selected rotorcraft engines and the resultant impact on compressor stall margin will be evaluated. Data will be used to develop analytical models for predicting the effects of inlet distortions and adverse environmental conditions such as dirt contamination, on the stall margin of a variety of compression system types. These models will be used to guide research and development efforts of advanced engine components.

4) Innovative Cycles.- In-depth analytical assessment studies will be conducted to evaluate the potential benefits to be gained by employing innovation cycles and engine system concepts such as regeneration, variable turbine geometry, convertible (compound) engines, differential gearing, and rotor tip drive methods. Other innovative concepts will also be sought. Attractive techniques will be experimentally evaluated in scale model or full scale component experiments. The resulting data will be used to predict the technical feasibility, including performance, weight, cost and size, and the potential applicability of selected candidate concepts to future rotorcraft vehicles. Integration and verification of these concepts in total systems will be evaluated in Phase IV of the propulsion program.

SYSTEMS INTEGRATION
II. ADVANCED ENGINES

PURPOSE: To evaluate and verify the performance potential and component matching characteristics of advanced technology components, such as compressors, combustors, turbines, and unconventional components in an actual engine environment. The achievement of the component integration objectives will be sought by exploring the two key technology task areas shown on Figure VIII-20.

BENEFITS: The key benefits that will be derived from this program element are related to greatly increasing future rotorcraft engine durability and reducing life cycle cost. Integration of the new component technologies in an actual engine will provide an improved understanding of how the "real world" hostile and cyclic environment affect component matching and performance. Thus, the ability to accurately predict the performance, performance retention, life, reliability, and maintainability of future engine designs will be substantially increased.

JUSTIFICATION: Problem areas unique to small engine components will be evaluated in component test rigs, which, for the most part, provide idealized inlet-test conditions to the test article. This is normally done so that the performance improvements being sought by applying advanced technology can be systematically explored and compared. However, these idealized inlet conditions are seldom realized when the components are integrated into an actual engine. Non-uniform inlet profiles which can vary considerably as a function of engine operating conditions and aircraft installation effects are normally the rule in actual service. These non-uniform profiles can significantly affect component performance and matching characteristics, particularly during transient operation such as engine accelerations. Furthermore, non-uniform component inlet conditions can impact critical parameters such as combustor pattern factor which has a direct effect on hot section durability and life. Furthermore, appli-

cation of advanced technology to compound engine applications for high speed, low disc loaded rotorcraft (Figure VIII-21) requires verification in a simulated system environment.

PROGRAM: A multi-phased contracted effort will be undertaken to integrate and evaluate the performance and matching characteristics of advanced technology components in an experimental small gas turbine engine. The components that will receive principal emphasis are the compressor, combustor, turbine, recouperators, and variable geometry. Other related factors such as tip clearances and tip treatment will also be incorporated.

Multiple contracts (2 or more) will be awarded to encompass two engine size ranges of approximately 500 and 2000 SHP. It is anticipated that existing engine centerlines will be used and the advanced technology components will be designed to replace existing components. Two distinct task areas consisting of the design, fabrication and experimental verification of advanced conventional and unconventional components (Figure VIII-22) installed in conventional and compound engines will be undertaken.

PROPULSION
PURPOSE

IMPROVE ENGINE AND POWER TRANSFER RELIABILITY/MAINTAINABILITY

IMPROVE ENGINE FUEL CONSUMPTION AT CRUISE POWER

IMPROVE ENVIRONMENTAL ACCEPTABILITY

REDUCE COSTS

FIGURE VIII-1

PROPULSION PROGRAM APPROACH

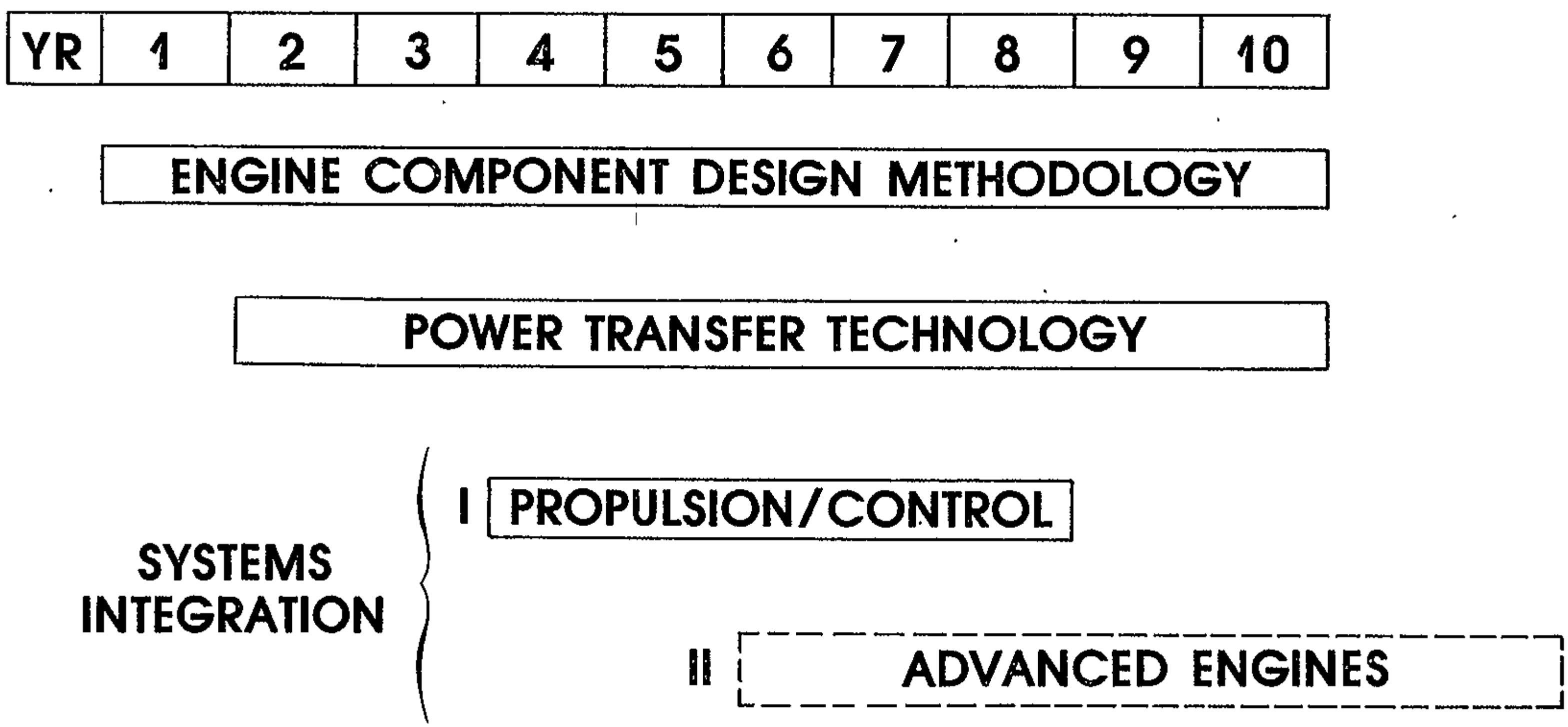
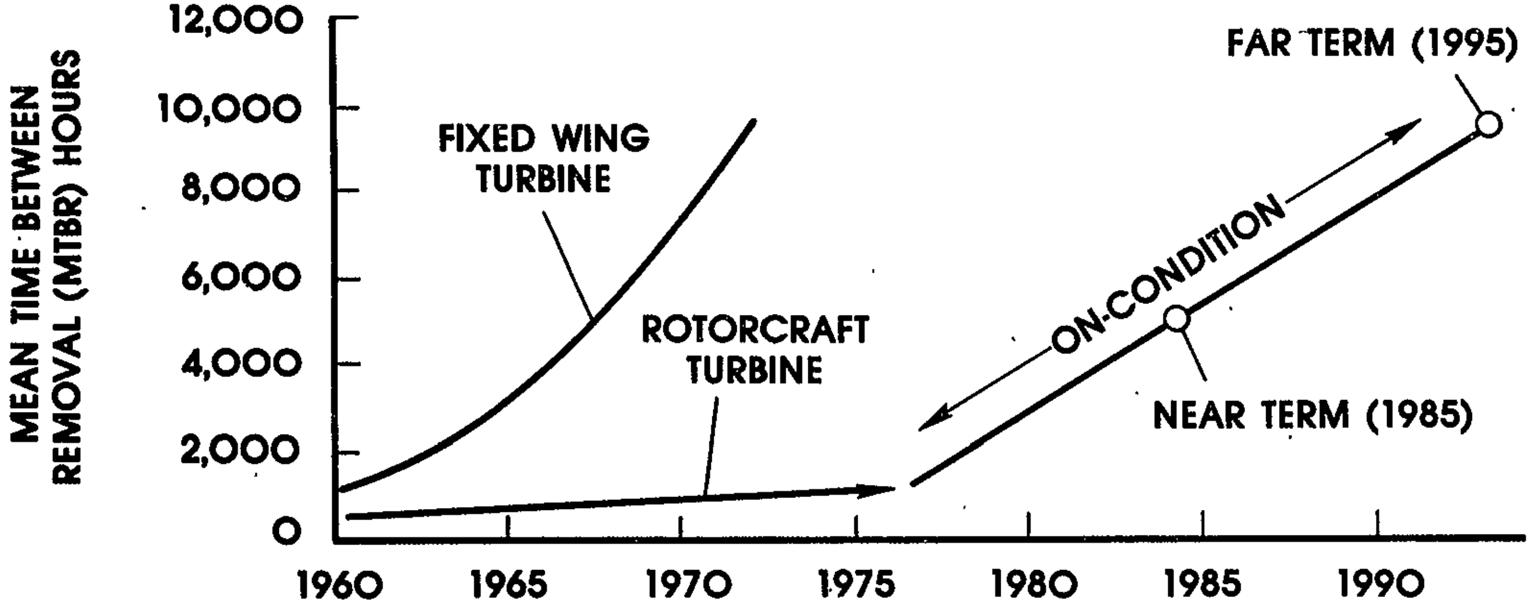


FIGURE VIII-2

ENGINE TECHNOLOGY GOALS



INCREASED ENGINE RELIABILITY THROUGH:

- IMPROVED ENGINE COMPONENT TECHNOLOGY
- IMPROVED CONTROLS TECHNOLOGY
- ADVANCED SYSTEMS MONITORING TECHNOLOGY

FIGURE VIII-3

SMALL ENGINE PROBLEMS

- MORE CENTRIFUGAL COMPRESSORS AND TURBINES
  - COMPLICATED FLOW FIELD
  - BOUNDARY LAYERS PREDOMINATE
- LOW ASPECT RATIO BLADING
  - END WALL EFFECTS PREDOMINATE
- ADVERSE SIZE EFFECTS
  - LOWER REYNOLDS NUMBERS
  - RELATIVELY POORER SURFACE FINISH,
  - HIGHER TOLERANCE & CLEARANCE SENSITIVITY
  - HIGHER SURFACE AREA-TO-VOLUME RATIOS

FIGURE VIII-4

ENGINE COMPONENT DESIGN METHODOLOGY

KEY TECHNOLOGY TASK AREAS

- ANALYTICAL DESIGN TECHNIQUES
- COMPRESSORS
- TURBINES
- COMBUSTORS
- ELECTRONIC CONTROLS
- DIAGNOSTICS

GOALS

- IMPROVE LIFE, RELIABILITY, AND MAINTAINABILITY
- REDUCE DESIGN, FABRICATION COSTS
- INCREASE EFFICIENCY
- REDUCE NOISE AND EMISSIONS

FIGURE VIII-5

CENTRIFUGAL COMPRESSORS

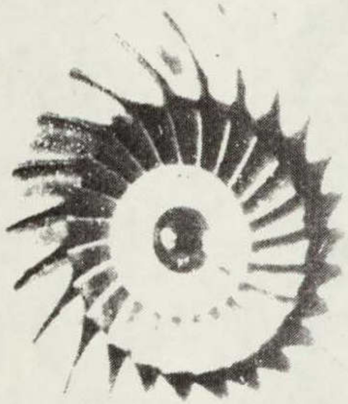
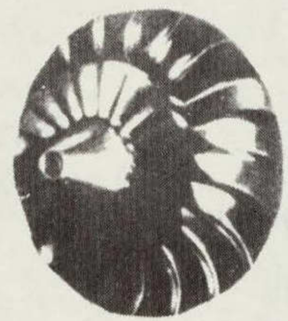
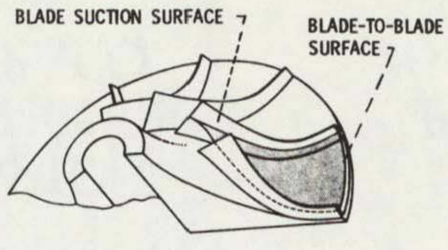
PRIOR YEARS	CURRENT	FY 1979	FUTURE
			?
4 TO 1 PRESSURE RATIO	6 TO 1 PRESSURE RATIO	8 TO 1 PRESSURE RATIO	20 TO 1 PRESSURE RATIO

FIGURE VIII-6

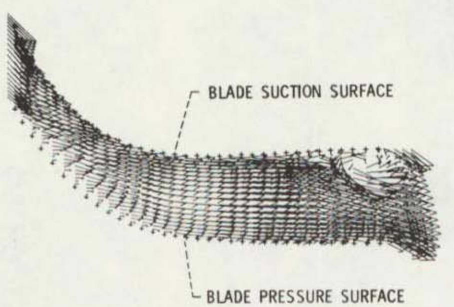
PROPULSION
CENTRIFUGAL COMPRESSOR DESIGN METHODOLOGY



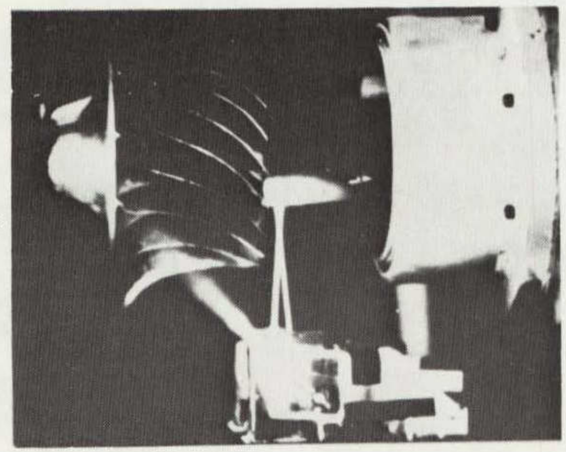
IMPROVED DESIGN

ADVANCED ANALYSES

EXPERIMENTAL VERIFICATION



COMPUTATIONAL FLUID MECHANICS
FLOW VECTOR PLOT



LASER DOPPLER VELOCITY

FIGURE VIII-7

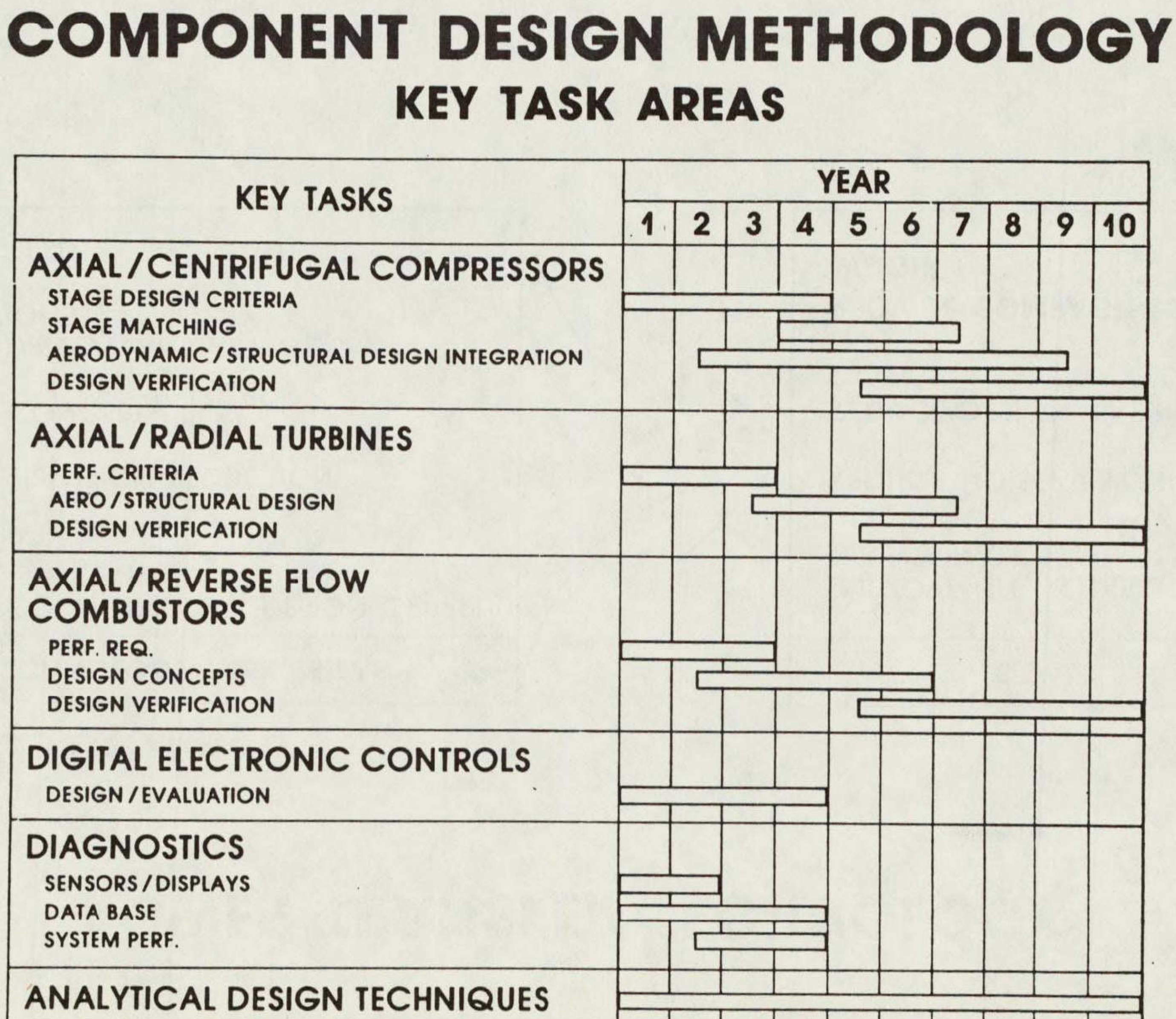


FIGURE VIII-8

POWER TRANSFER TECHNOLOGY

KEY TECHNOLOGY TASK AREAS

ADVANCED COMPONENTS & DESIGN CRITERIA

DIAGNOSTICS

NOISE AND VIBRATION REDUCTION

ADVANCED CONCEPTS

- TRACTION DRIVE/PLANETARY GEAR COMBINATIONS
- VARIABLE SPEED

GOALS

IMPROVE LIFE, RELIABILITY, MAINTAINABILITY

REDUCE NOISE/VIBRATION

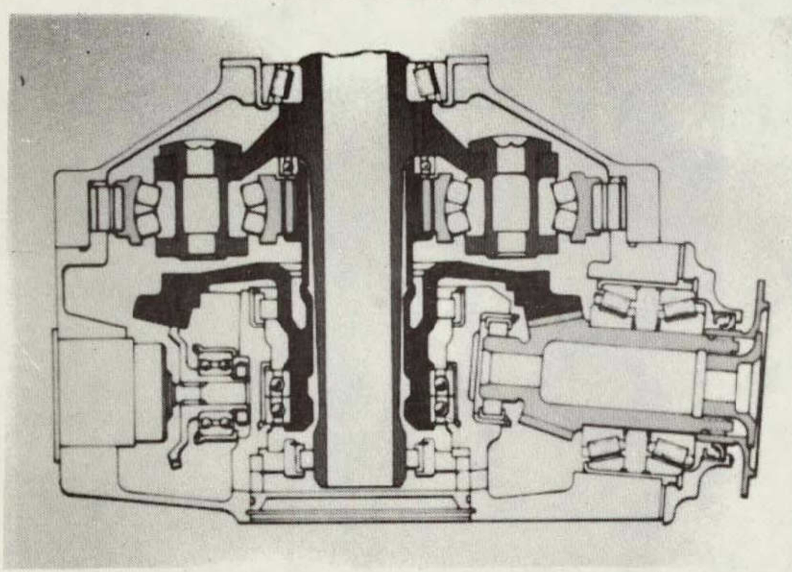
REDUCE DESIGN, FABRICATION COSTS

PROVIDE COMPACTNESS, LIGHT WEIGHT

FIGURE VIII-9

POWER TRANSFER TECHNOLOGY
ADVANCED CONCEPTS

CONVENTIONAL TRANSMISSION



ADVANCED TRANSMISSION

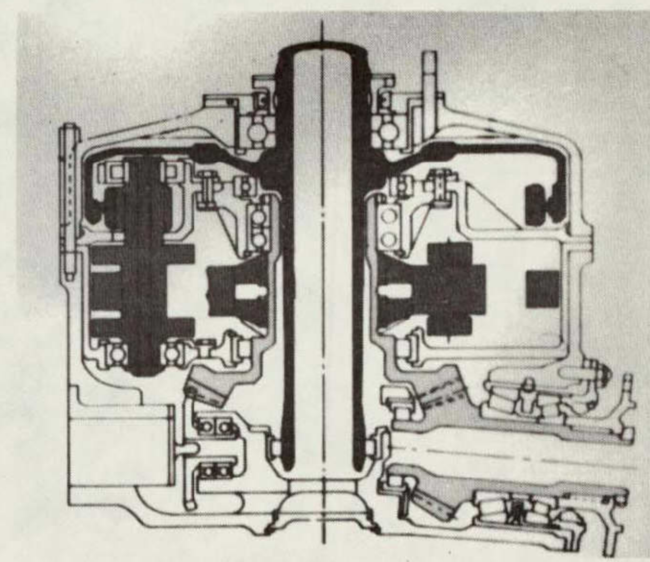
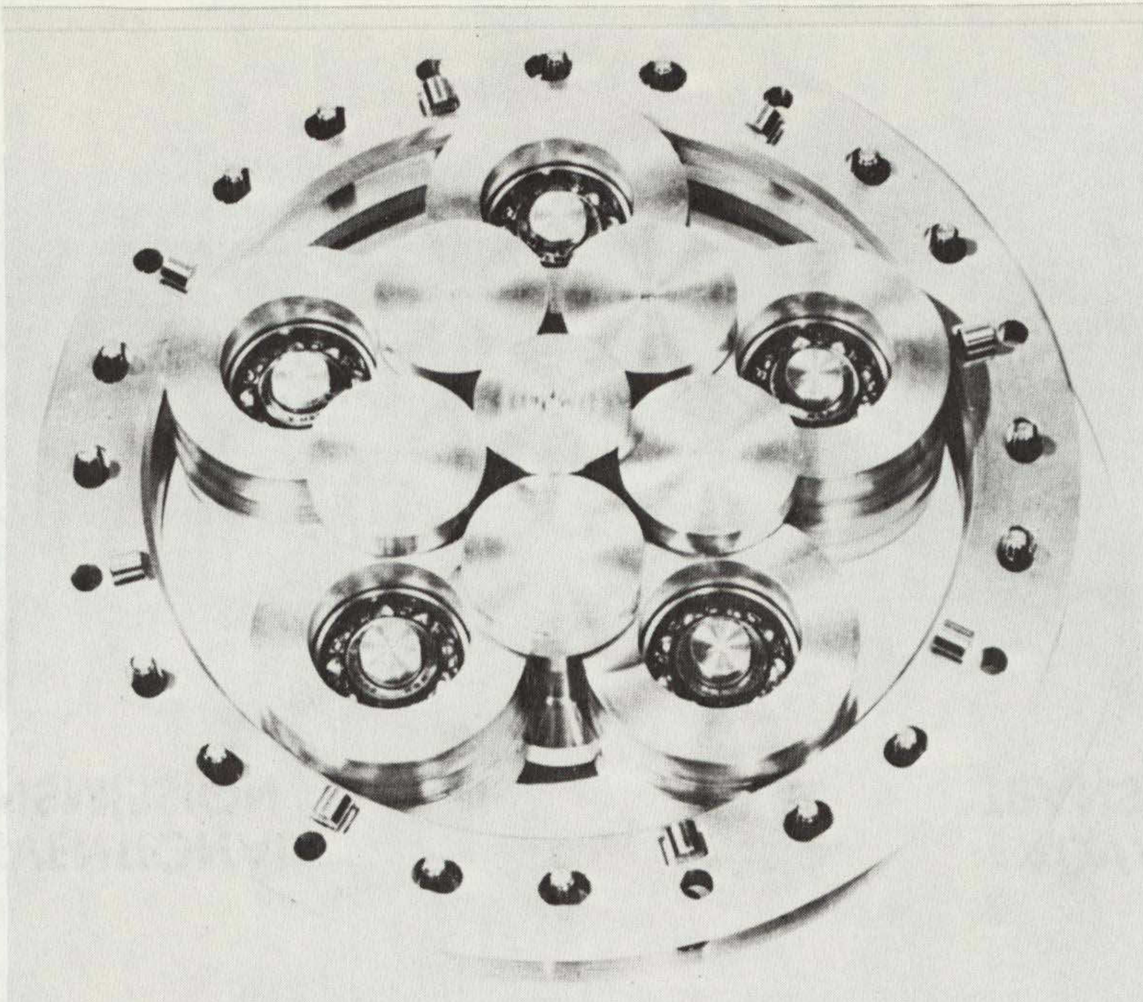


FIGURE VIII-10

TRACTION DRIVE TRANSMISSION SYSTEMS



15:1 SPEED REDUCTION

FIGURE VIII-11

POWER TRANSFER TECHNOLOGY
ADVANCED HELICOPTER TRANSMISSION TECHNOLOGY

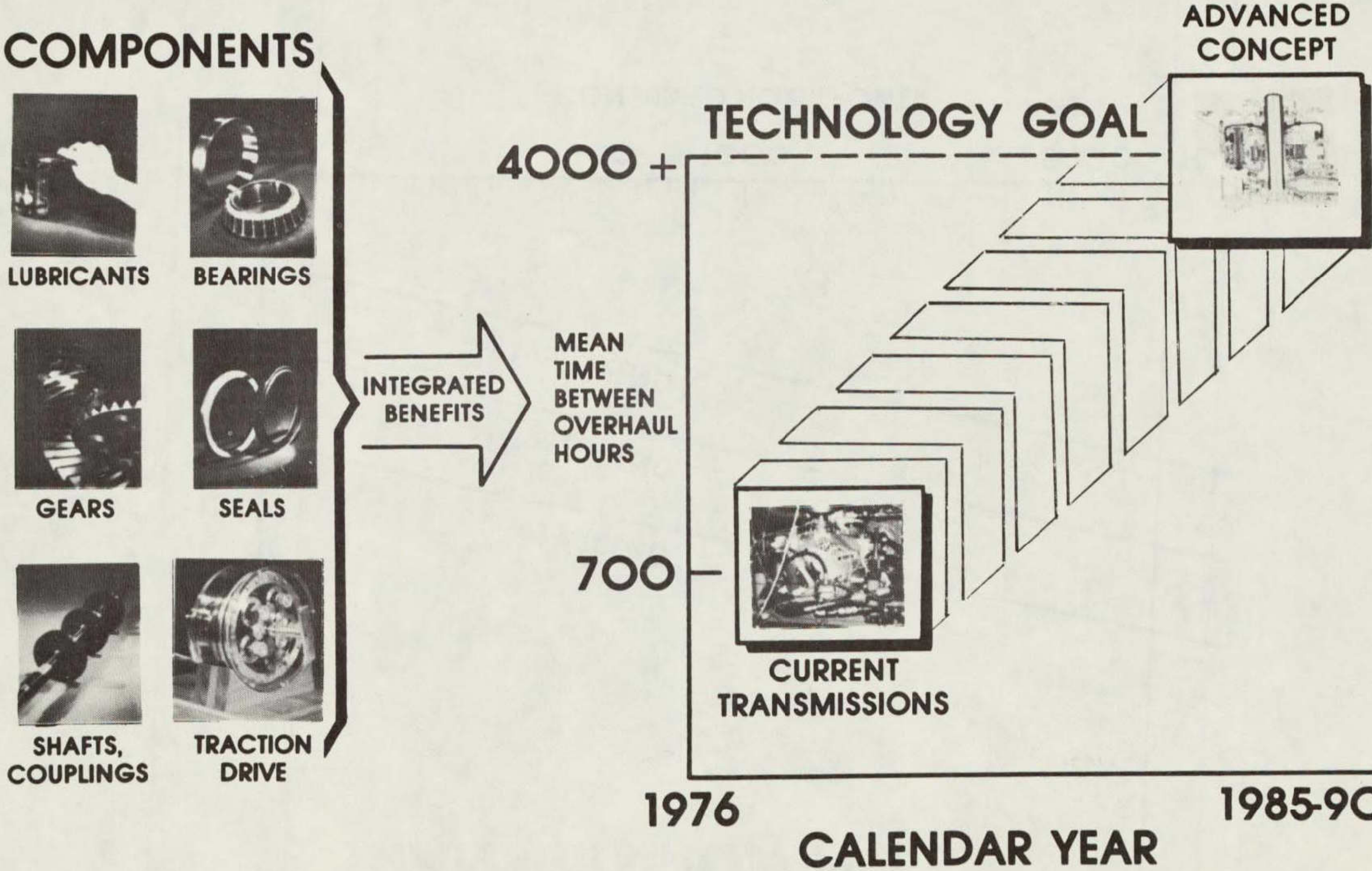


FIGURE VIII-12

TRANSMISSION NOISE

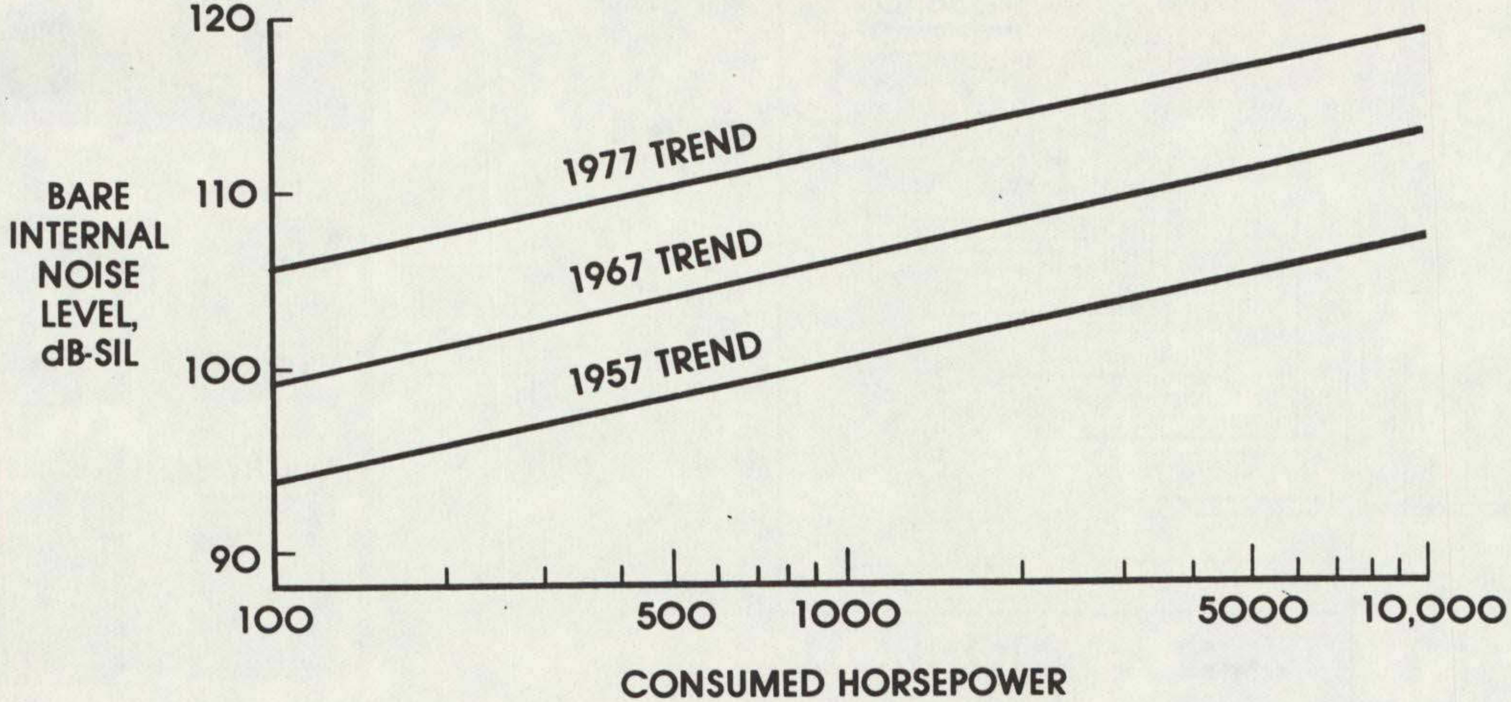


FIGURE VIII-13

POWER TRANSFER TECHNOLOGY
KEY TASK AREAS

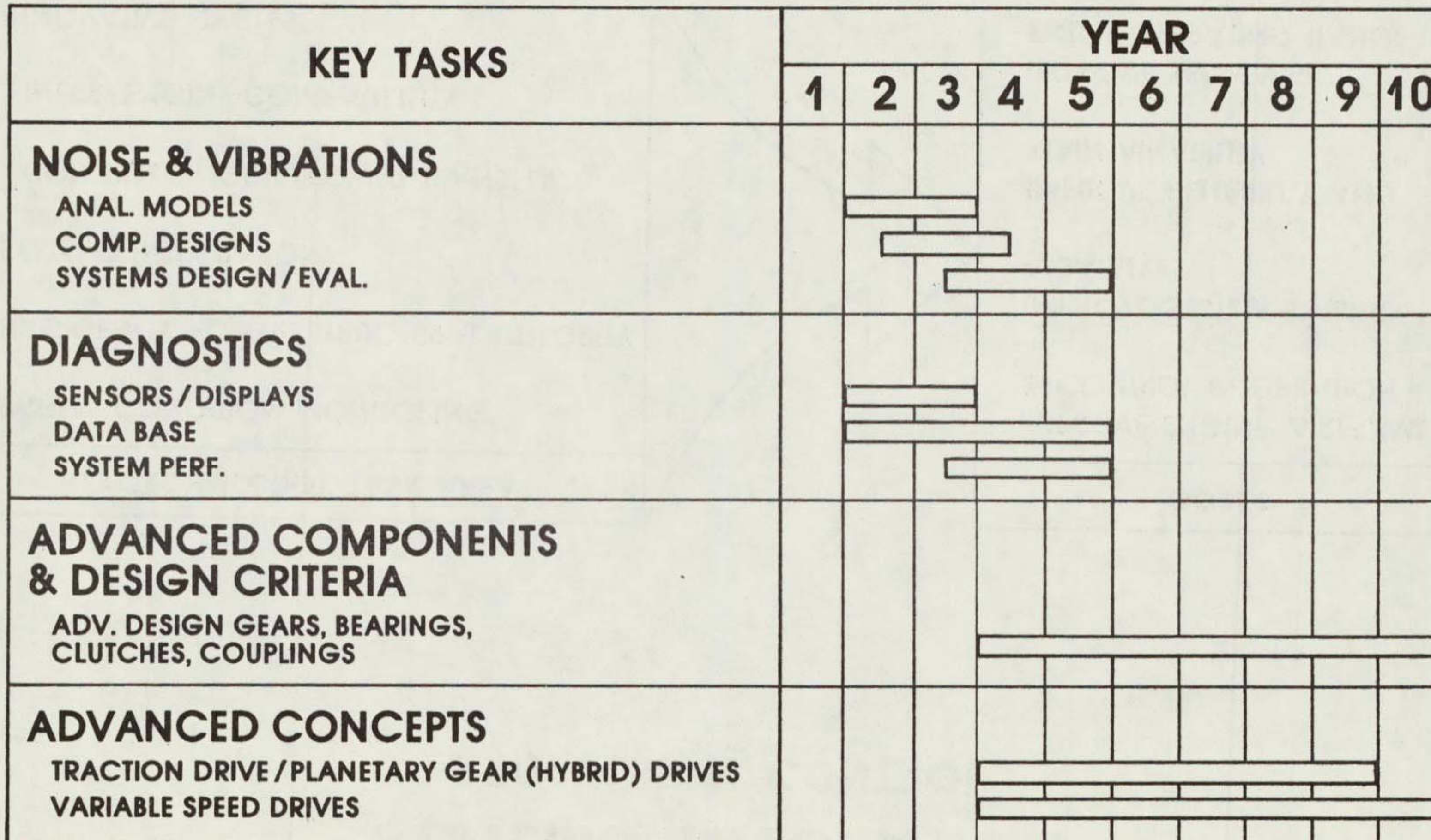


FIGURE VIII-14

SYSTEMS INTEGRATION

PROPULSION/CONTROL

KEY TECHNOLOGY TASK AREAS

- SYSTEM CONDITION MONITORING
- EMERGENCY POWER/STRUCTURAL INTEGRITY
- SYSTEMS INTEGRATION
  - CONTROL/ENGINE/POWER TRANSFER
  - INLET/ENGINE COMPATIBILITY
- INNOVATIVE CYCLES

GOALS

- IMPROVE ENGINE, AIRFRAME, & CONTROL INTEGRATION
- IMPROVE SYSTEM STABILITY & SAFETY
- IMPROVE RELIABILITY AND MAINTAINABILITY
- IMPROVE SFC OVER ENTIRE OPERATING RANGE

FIGURE VIII-15

MODERN TURBOSHAFT ENGINE

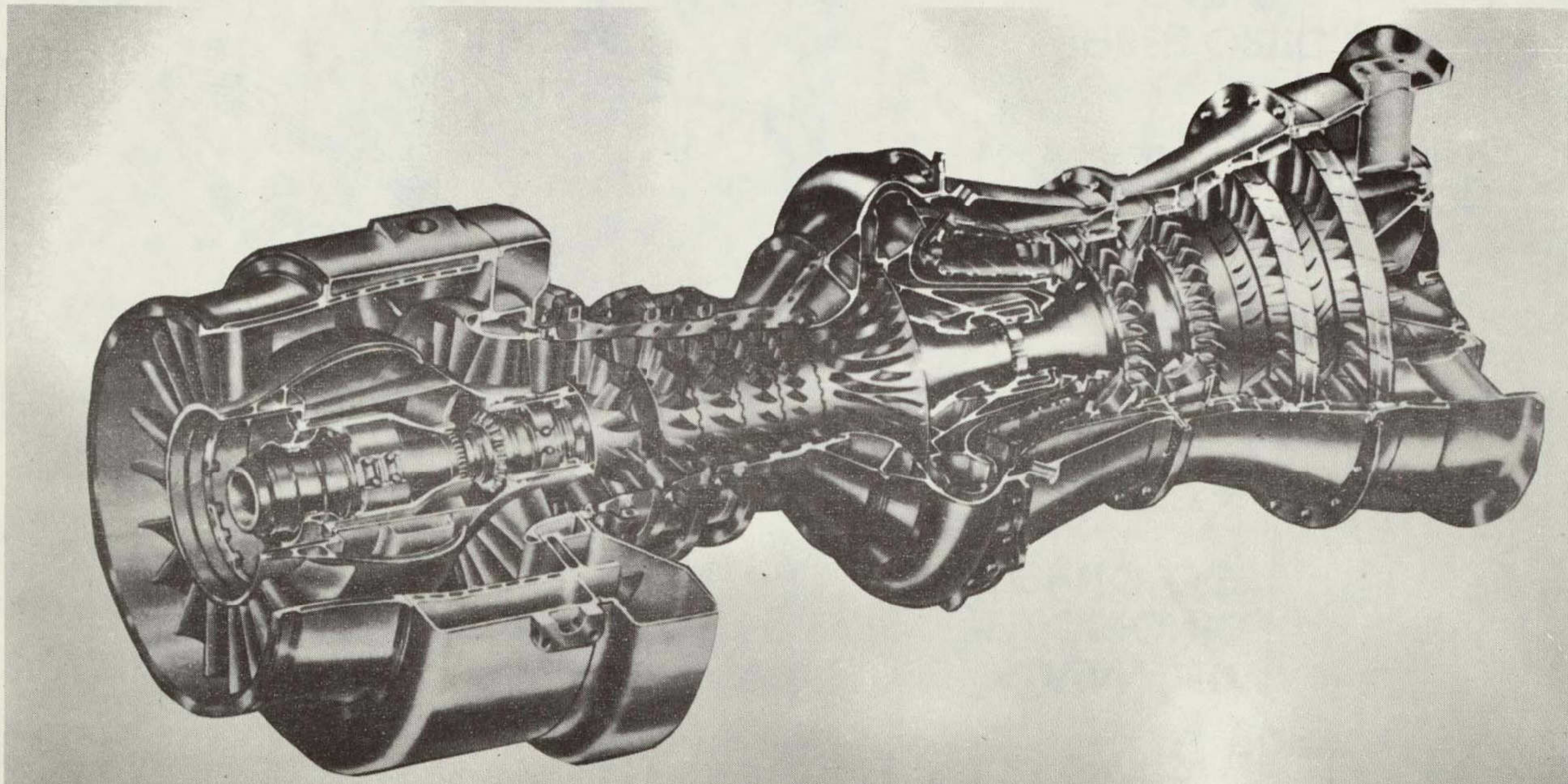


FIGURE VIII-16

INTEGRATED ELECTRONIC DIGITAL CONTROLS

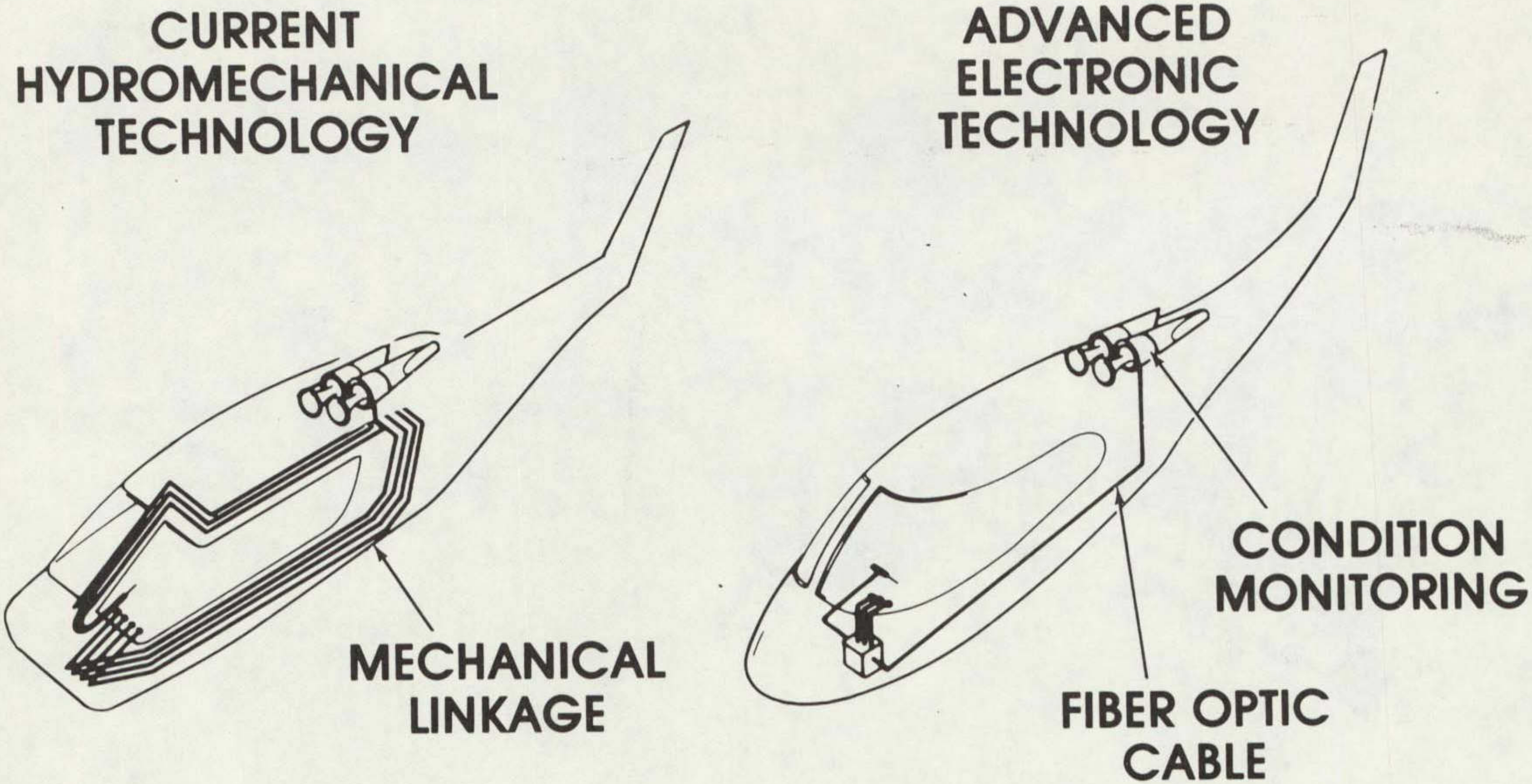


FIGURE VIII-17

ROTORCRAFT ENGINE SPECIFIC FUEL CONSUMPTION CHARACTERISTICS

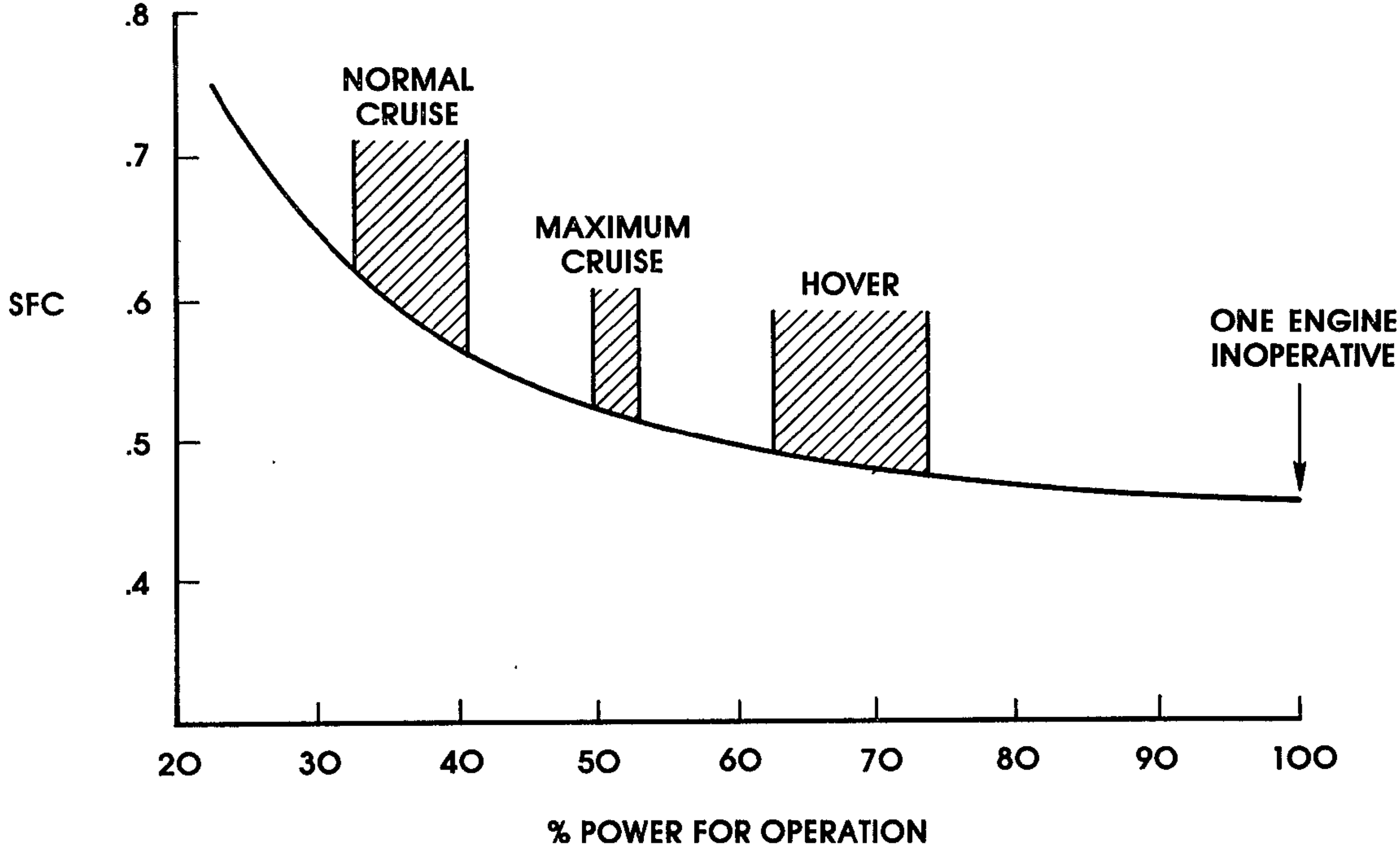


FIGURE VIII-18

SYSTEMS INTEGRATION

PROPULSION/CONTROL SUMMARY

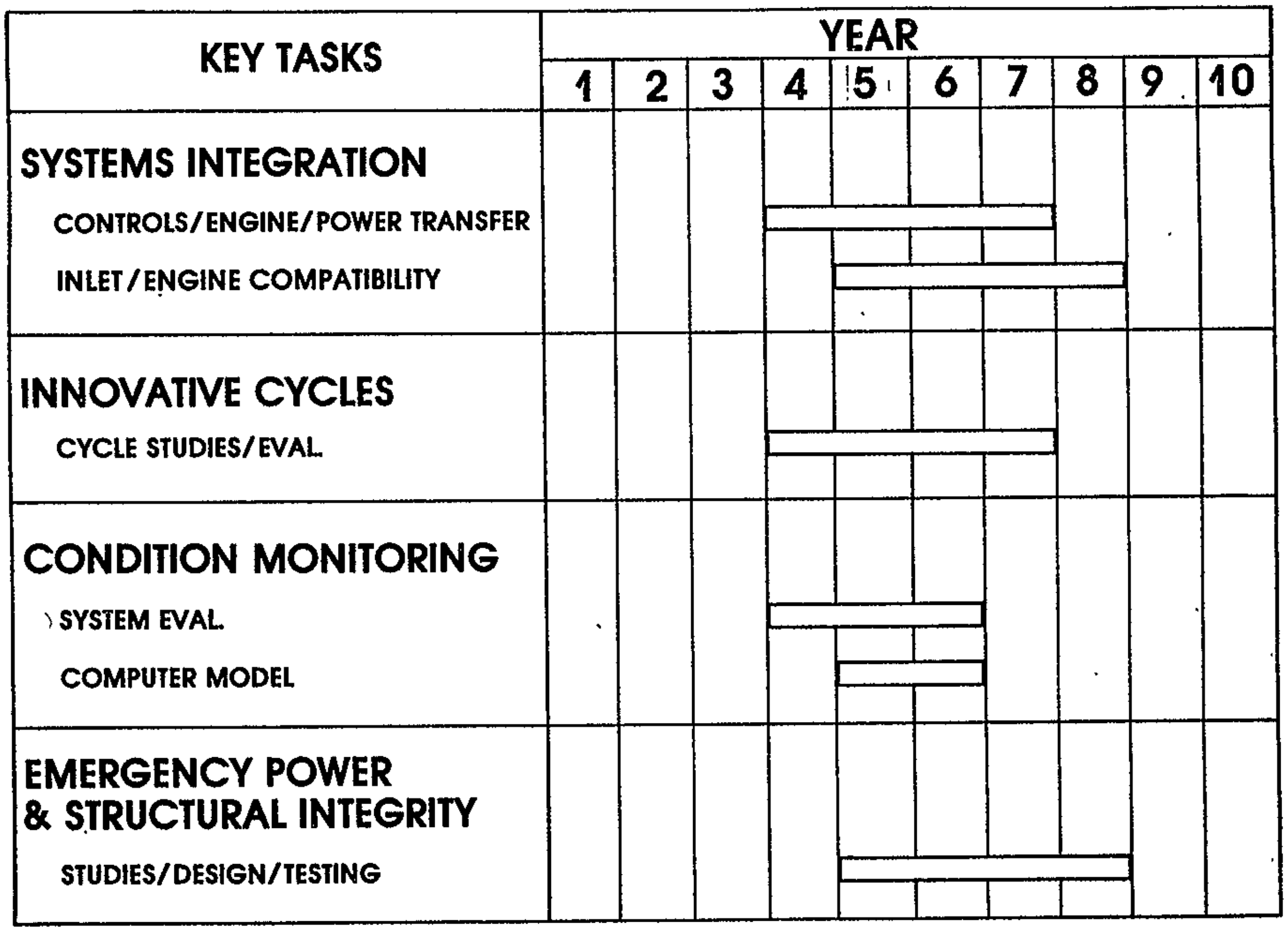


FIGURE VIII-19

SYSTEMS INTEGRATION
ADVANCED ENGINES

KEY TECHNOLOGY TASK AREAS	GOALS
ADVANCED COMPONENTS/ ENGINE VERIFICATION	PROVIDE "PROOF-OF-CONCEPT" IN REAL WORLD ENVIRONMENT
UNCONVENTIONAL COMPONENTS/ ENGINE VERIFICATION	DEMONSTRATE STATE OF READINESS OF ADVANCED TECHNOLOGY COMPONENTS

FIGURE VIII-20

COMPONENT INTEGRATION
POTENTIAL COMPOUND ROTORCRAFT PROPULSION SYSTEM

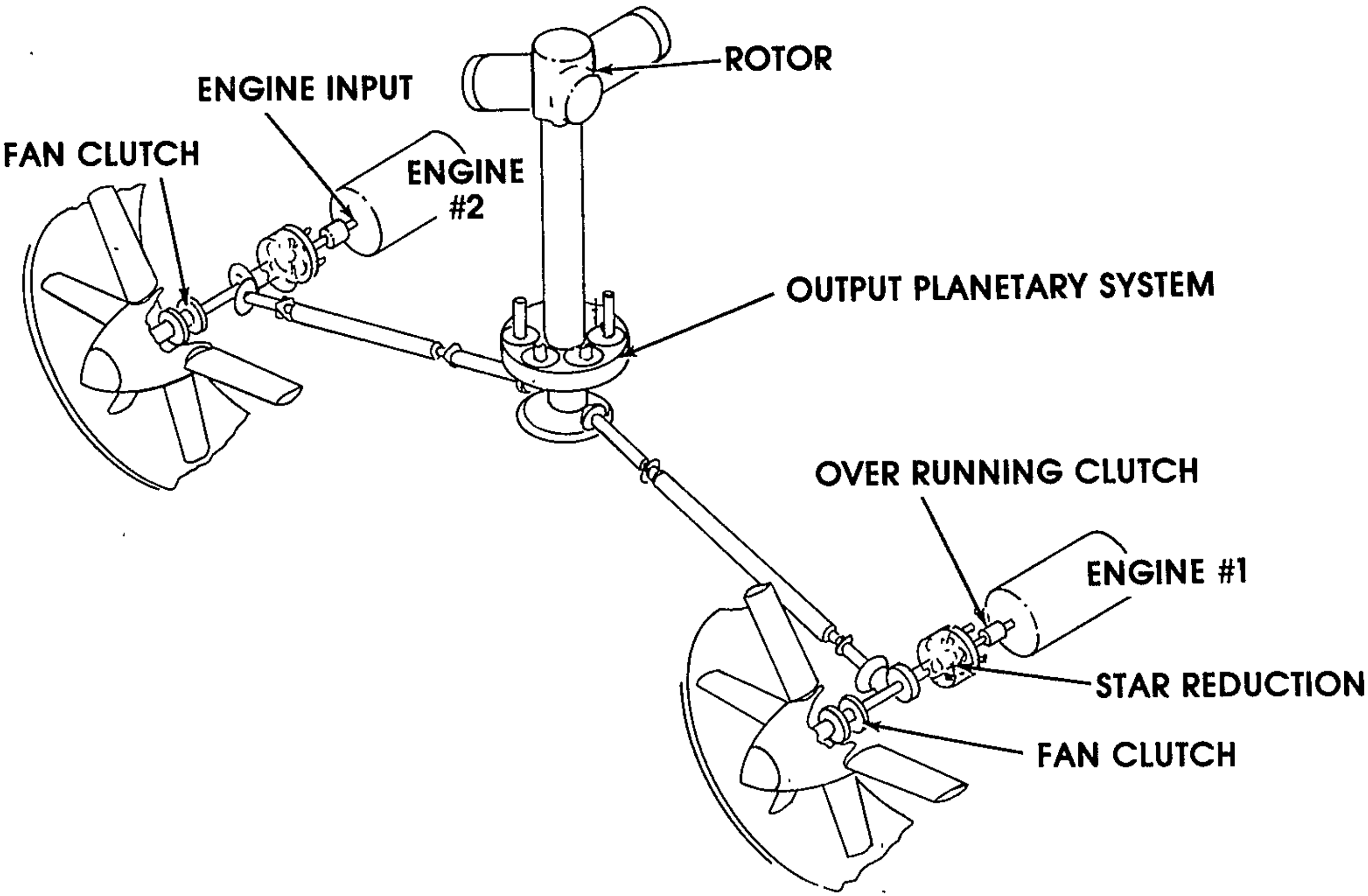


FIGURE VIII-21

SYSTEMS INTEGRATION

ADVANCED ENGINES
SUMMARY

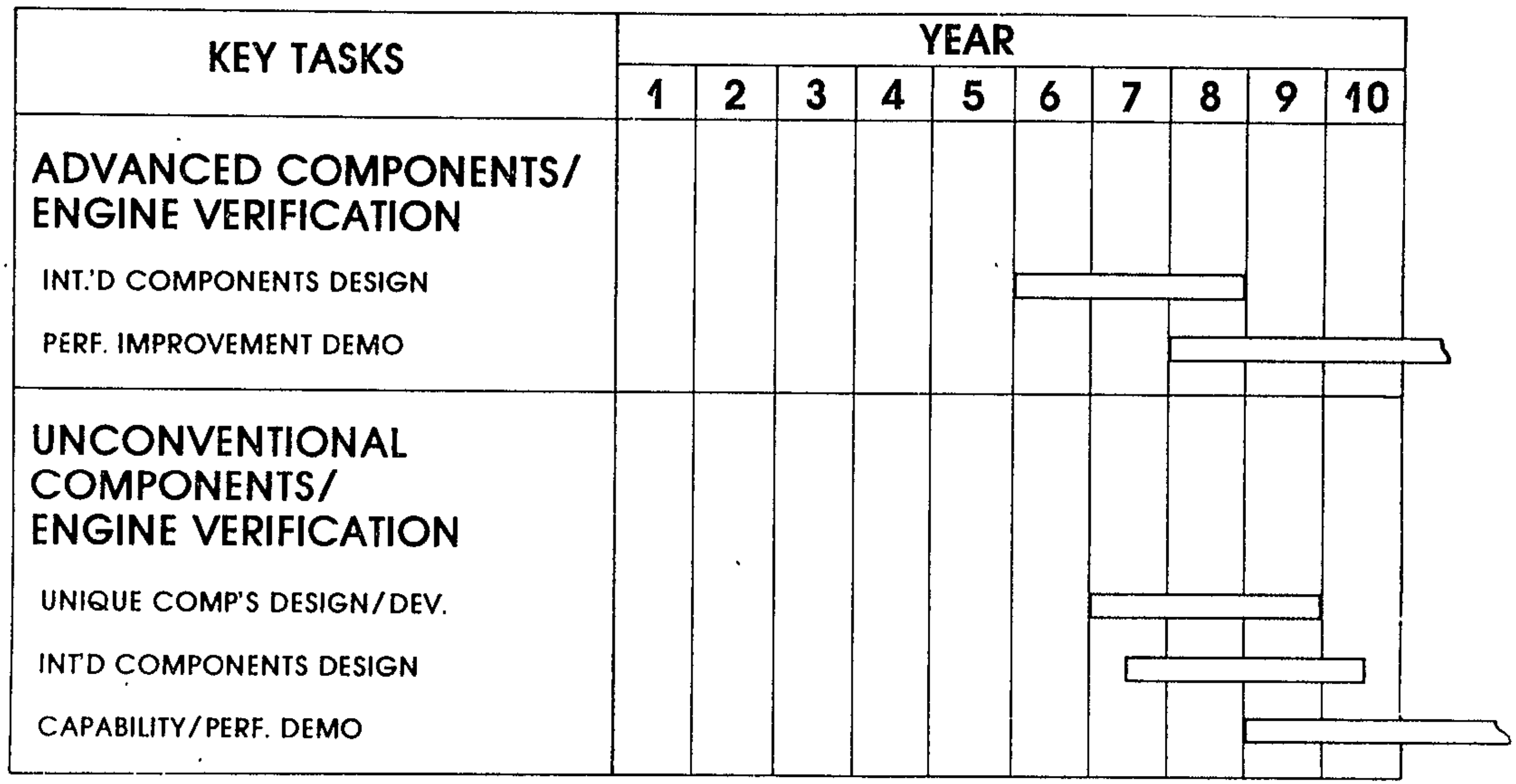


FIGURE VIII-22

VEHICLE CONFIGURATIONS

In response to the growing civil market opportunities, the world helicopter industry is introducing new civil designs in the light and medium, single and twin turbine class. It is expected that the late 1980's and 1990's will present needs and opportunities for advanced vehicle configurations. High speed, low disk loading rotorcraft and large cargo, transport, heavy lift vehicles appear to be a natural follow-on to the current designs. In order to assure that the U.S. has the necessary technology available to pursue future high speed and large rotorcraft options, a continuing research effort is required.

In the case of high speed, low disk loading rotorcraft, there has been a hiatus in the research activity which was being pursued in the late 1960's. Now, the need for increased speed in many civil and military missions reiterates the need for increased research emphasis in this area.

Opportunities are also beginning to emerge in the civil marketplace for larger transport, cargo and heavy external lift rotorcraft. The catalyst for this market is the oil resource exploration and development industry. Transporting crews and equipment over increasing distances to off-shore oil rigs has opened the market for the medium size cargo/transport class of vehicle. As a natural follow-on to this activity, there is serious consideration being given to the introduction of medium to large transport helicopters in the city-to-city short haul system -- particularly in Europe, where the 200-mile London to Paris route is under consideration.

In the late 1980's and the 1990's large civil transports may emerge to serve a growing short-haul market in Europe and perhaps in the U.S. Northeast. This transport utilization may be spurred by a slowdown in the construction of major air terminals in close proximity to large cities. Additional opportunities for large, heavy lift vehicles will likely emerge as a natural outcome of the growing needs of the cargo, construction, logging and resource exploration industries.

The following sections address a research plan aimed at establishing a technology base in high speed and large rotorcraft (Figure IX-1). The overall purpose, benefits and approach (Figures IX-2 and IX-3) are keyed to concept evaluations using existing vehicles and conducting ground based studies of advanced concepts. As the concept assessments mature, large scale ground based testing would follow. In the outyears, if warranted, research vehicle flight testing would be the result of downstream decisions.

HIGH SPEED CONCEPTS

PURPOSE: The purpose of this program task is to develop and evaluate critical technology for future high speed rotorcraft concepts.

BENEFIT: The goal of this research is to provide validated technology for promising high speed rotorcraft concepts to allow users and industry to make minimum risk decisions regarding vehicle development options.

JUSTIFICATION: There are increasing signs that speed will return as an important factor in selected civil and military missions. Off-shore oil exploration is reaching beyond the normal capability of the pure helicopter. Many potential intercity routes also fall in this category. Eventually, the productivity and range of today's production designs will be pressed to the limit. There are a number of promising rotorcraft concepts that require technical assessment.

PROGRAM: The proposed program involves utilization of existing research aircraft and of ground-based studies and testing to develop a data base. Detailed studies will be conducted to enable a rational assessment of the potential of new concepts. The research would involve in-house tests, analysis and studies. Close coordination with industry will be attained through contracted research efforts.

The initial tasks would be oriented toward concept technology evaluation involving the following three activities:

Extended flight test (Figure IX-4). The ongoing proof-of-concept flight tests of the XV-15 Tilt Rotor Research Aircraft will be extended to acquire a thorough documentation of tilt rotor aerodynamics, flying qualities, stability and control, and structural loads characteristics. This extended testing follows the currently planned NASA/Army proof-of-concept program. A similar program would be carried out on the Advancing Blade Concept (ABC) vehicle.

Ground based studies and tests (Figure IX-5). Feasibility and preliminary design studies of high speed concepts will be done to define the capabilities of advanced versions of existing concepts and new conspts. These studies will be supported by ground based tests and simulation of critical flight control systems, rotor systems, etc. Aircraft concepts to be considered include the X-wing, advanced tilt rotor, advanced ABC, and the winged compound. In regard to the compound studies the Rotor Systems Research Aircraft provides an excellent facility for flight research and verification of compound technology.

Assessment of future potential (Figure IX-6). Trade-off studies of the various promising high speed rotorcraft concepts will be conducted. These studies will be based on the flight and ground based studies and tests. The trade-offs would identify relative potential of the various vehicles and define technology gaps which would be addressed in future research efforts. The results of this overall effort would be used to form the basis of a downstream decision regarding flight testing of advanced configurations.

In order to validate the more promising technology for high speed rotorcraft a second phase effort would follow the decision to proceed to flight test. This phase would involve design and fabrication of full-scale hardware, ground-based testing to flight qualify the systems, such as advanced rotor and control systems, and then proceed to flight research with the advanced systems using available research aircraft.

The key high speed tasks are summarized in Figure IX-7.

LARGE ROTORCRAFT CONCEPTS

PURPOSE: The purpose of this program task is to develop and evaluate critical technology for future civil and military applications to cargo, transport and heavy lift missions.

BENEFITS: The proposed research would provide a broad based technology in large rotorcraft concepts and systems to enable potential users and manufacturers to make minimum risk decisions regarding vehicle development options.

JUSTIFICATION: The current trends in vehicle size and utilization suggest that, if continued, the late 1980's and early 1990's will see the introduction of large rotorcraft in cargo, transport and a wide variety of heavy lift applications. The technology for large vehicles is not well established in the free world at the present time.

PROGRAM: Figures IX-8 through IX-10 illustrate the type of configurations to be considered in this segment of the program. The configurations include conventional vehicles such as the single and tandem rotor helicopter and the tilt rotor concept. The tilting and nontilting quad rotor configuration would also be assessed for application to cargo/transport and very heavy lift applications, respectively. In general the research will involve concept studies (Figure IX-11) and ground based and flight testing with available hardware. Future options would include consideration of large scale ground based testing of selected advanced configurations (Figure IX-8).

Assessment of Future Potential. The initial effort will involve the assessment of various options for the heavy lift, cargo and transport mission. A key consideration of the heavy lift studies will be the feasibility of providing a high speed ferry capability for heavy lift vehicles. One possibility is the use of the quad tilt rotor vehicle which would allow heavy lift hover to be combined with high-speed

cruise with the rotors in a propelling mode similar to the current tilt rotor configuration. Convertible rotor/wing aircraft configurations will also be considered. Model tests and simulation studies will be conducted. Exploratory flight tests of the multi-vehicle concept will be conducted using avionic systems technology developed under the Flight Control and Avionic Systems element of this program.

XCH-62A Assets. Figure IX-12 shows the XCH-62A aircraft drive system which is now in storage as a result of the termination of the Heavy Lift Helicopter prototype program in 1976. At the request of the Aeronautics and Space Engineering Board, NASA formed an ad hoc team, including DOD representatives, to look into the potential research utilization of the XCH-62A assets. The team's recommendations included extended ground testing of the XCH-62A transmission and combiner box. The proposed large rotorcraft program recognizes the merit of this recommendation as a research effort on large transmissions which has future application to heavy lift and large transport rotorcraft as well as potential payoff in regard to the high power transmission technology which could also be applied to shaft driven lift/cruise fan concepts (Figure IX-13).

Advance Vehicle Concept Verification. The earlier phases of concept studies, exploratory ground based testing, simulation and the generation of a technical data base would be followed by large scale ground based testing of selected subsystems such a rotor concepts, control systems, etc. If these tests demonstrate potential benefits for application to advanced large rotorcraft, consideration will be given to the need for an experimental vehicle to integrate and demonstrate the technology advances.

In the third year a decision point is proposed for deciding on proceeding with the final assembly and research flight testing of the XCH-62A vehicle (Figure IX-14). This effort

has high potential payoff for providing a technology base and flight research experience using a large rotorcraft of opportunity.

Figure IX-15 is a summary of the large rotorcraft key tasks.

VEHICLE CONFIGURATIONS

HIGH SPEED CONCEPTS

LARGE ROTORCRAFT CONCEPTS

FIGURE IX-1

VEHICLE CONFIGURATIONS

PURPOSE

DEVELOP AND EVALUATE CRITICAL TECHNOLOGY FOR FUTURE HIGH SPEED AND LARGE ROTORCRAFT CONCEPTS

BENEFIT

PROVIDE VALIDATED TECHNOLOGY FOR PROMISING CONCEPTS TO ALLOW USERS AND INDUSTRY TO MAKE MINIMUM-RISK DECISIONS REGARDING FUTURE VEHICLE DEVELOPMENT OPTIONS

FIGURE IX-2

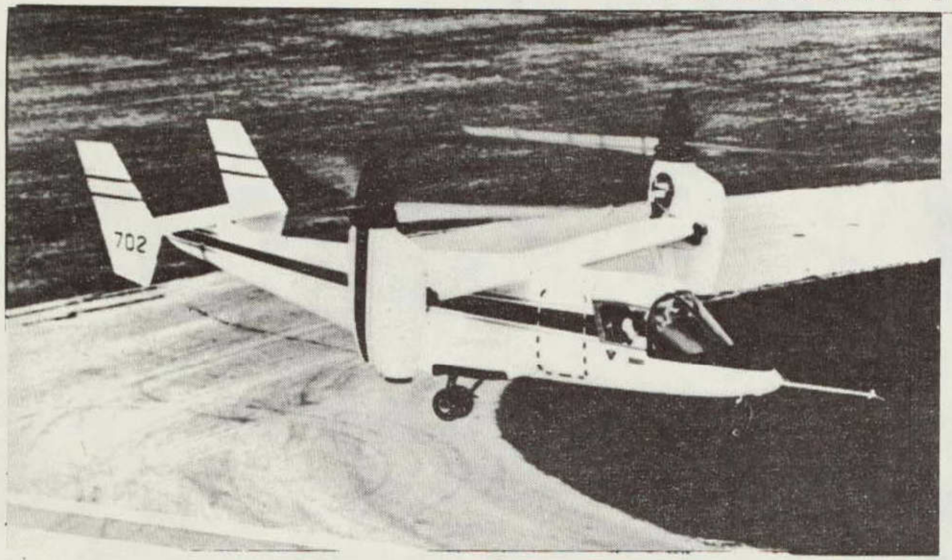
VEHICLE CONFIGURATIONS

APPROACH

PHASE I	CONCEPT EVALUATION USING EXISTING VEHICLES TOGETHER WITH GROUND BASED STUDIES AND TESTS
PHASE II	LARGE SCALE ADVANCED TECHNOLOGY GROUND AND FLIGHT TESTS
PHASE III	EXPERIMENTAL VEHICLE DESIGN, FABRICATION AND FLIGHT

FIGURE IX-3

HIGH SPEED CONCEPTS
EXTENDED FLIGHT TEST



ARMY / NASA XV-15
TILT ROTOR RESEARCH
AIRCRAFT

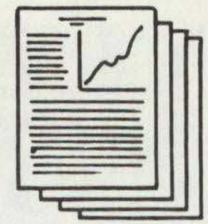
ARMY / NAVY / NASA
ADVANCING BLADE CONCEPT
(ABC)

FIGURE IX-4

HIGH SPEED CONCEPTS
PRELIMINARY STUDIES AND TESTS

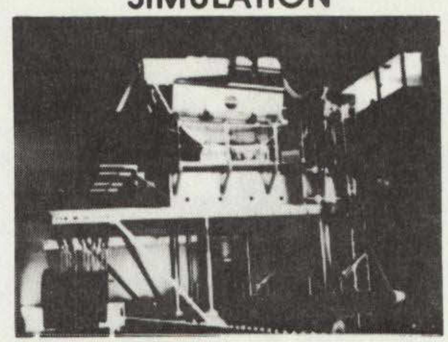
CONCEPTS

SELECTED
PRELIMINARY DESIGN STUDIES



MODEL TESTS

SIMULATION



PRELIMINARY
EVALUATION
OF
ADVANCED
TECHNOLOGY
OPTIONS

FIGURE IX-5

HIGH SPEED CONCEPTS
ASSESSMENT OF FUTURE POTENTIAL

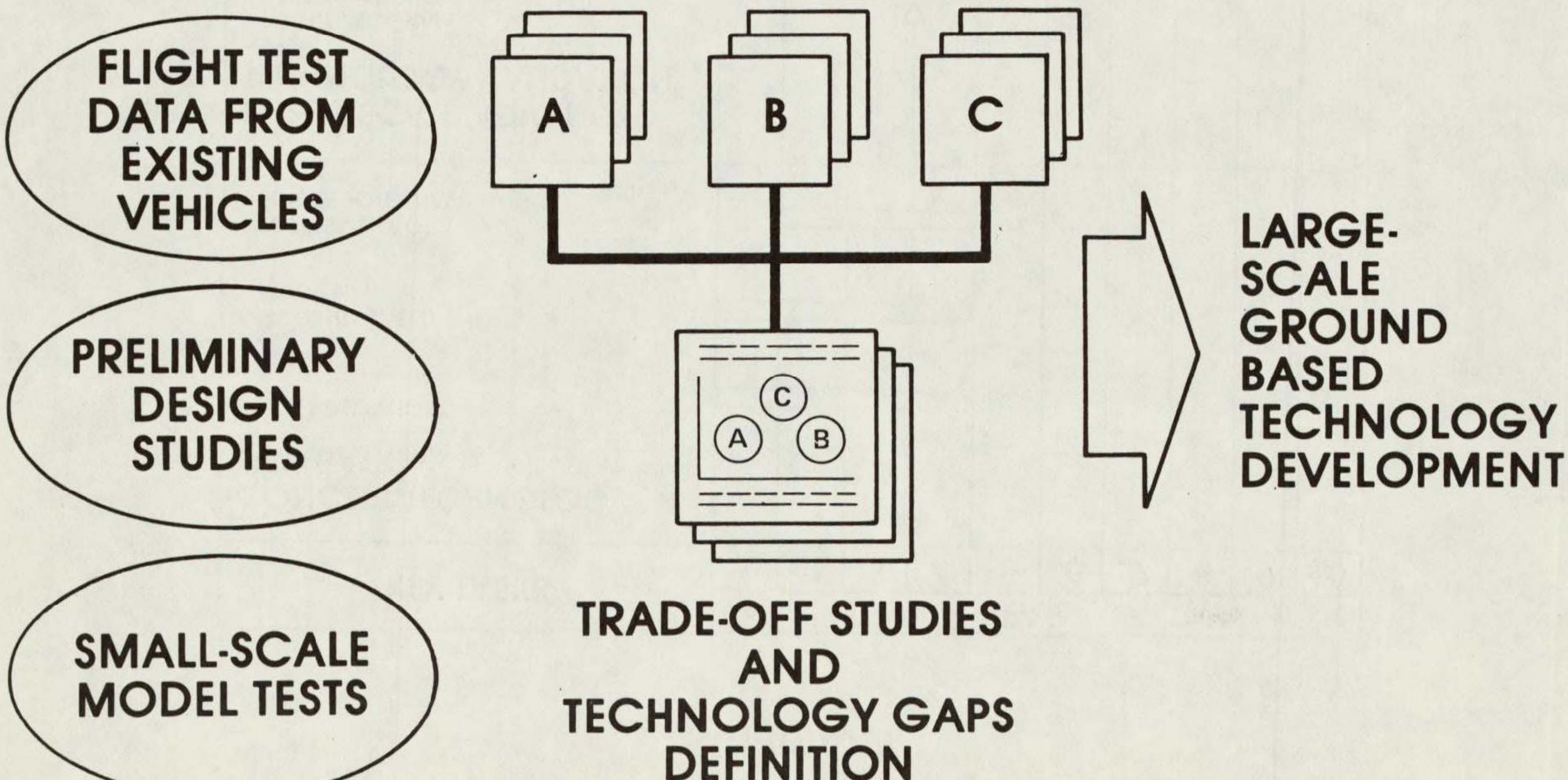


FIGURE IX-6

HIGH SPEED
SUMMARY

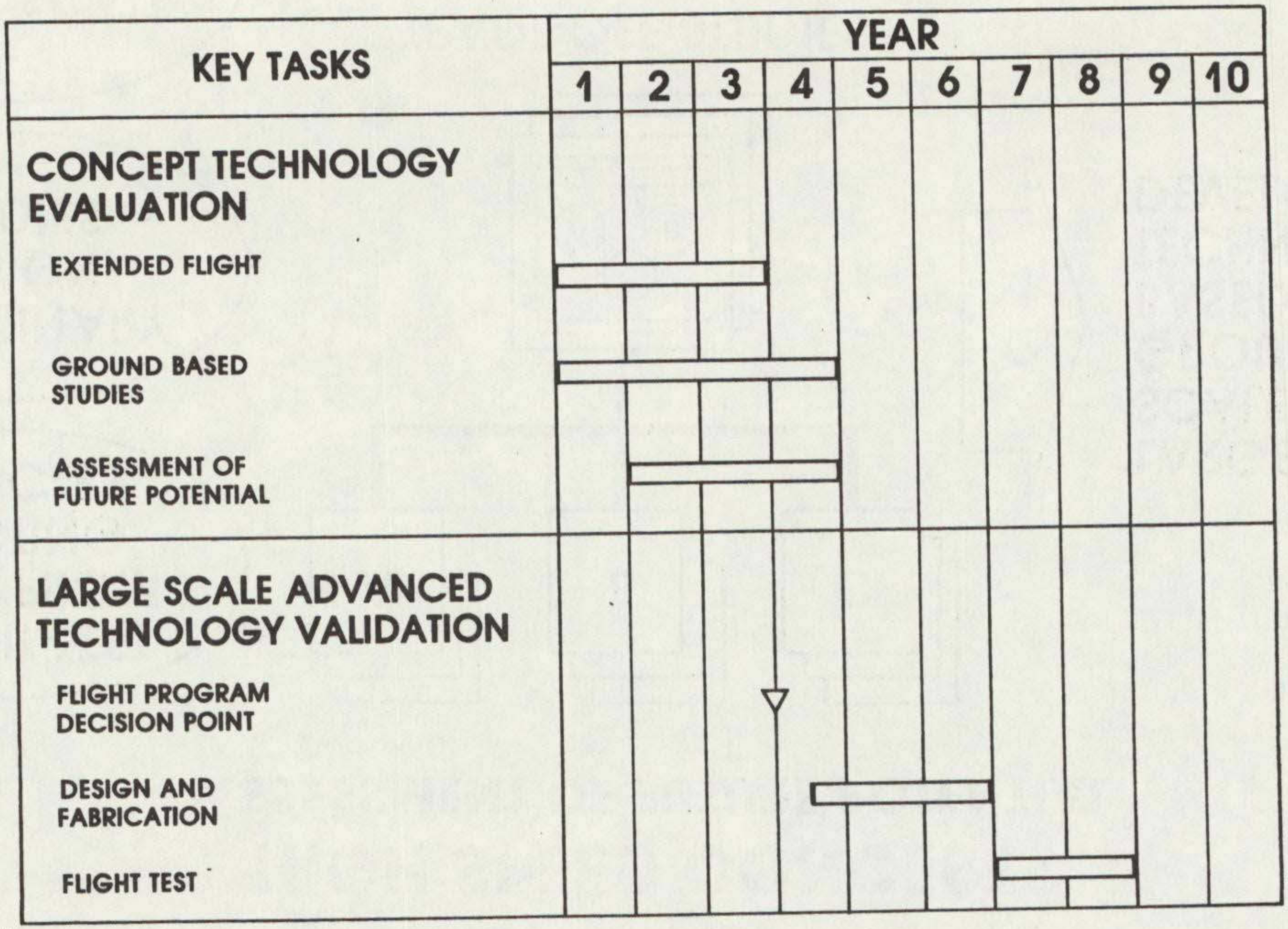


FIGURE IX-7

LARGE ROTORCRAFT
CONCEPTS

SINGLE ROTOR
- SHAFT DRIVEN HELICOPTER
- CONVERTIBLE DRIVE COMPOUND
- WARM CYCLE TIP-REACTION DRIVE

TANDEM

TILT ROTOR

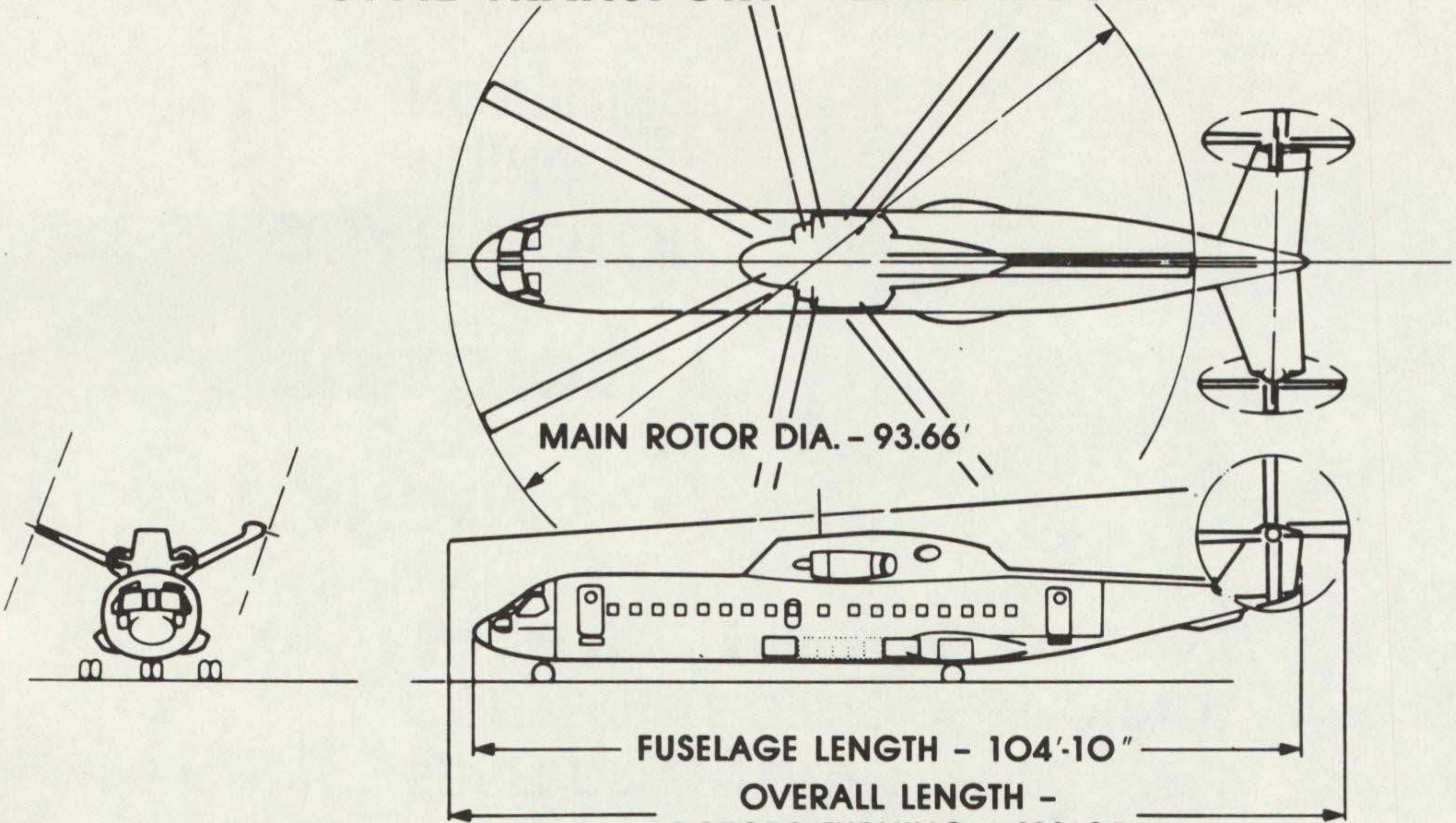
QUAD ROTOR
- TILTING
- NONTILTING

MULTI-LIFT

FIGURE IX-8

CIVIL TRANSPORT

CIVIL TRANSPORT — LATE 1980's



90 TO 100 PASSENGERS

REF: NASA CR 2532
FEBRUARY 1975

FIGURE IX-9

LARGE ROTORCRAFT
CIVIL HEAVY LIFT

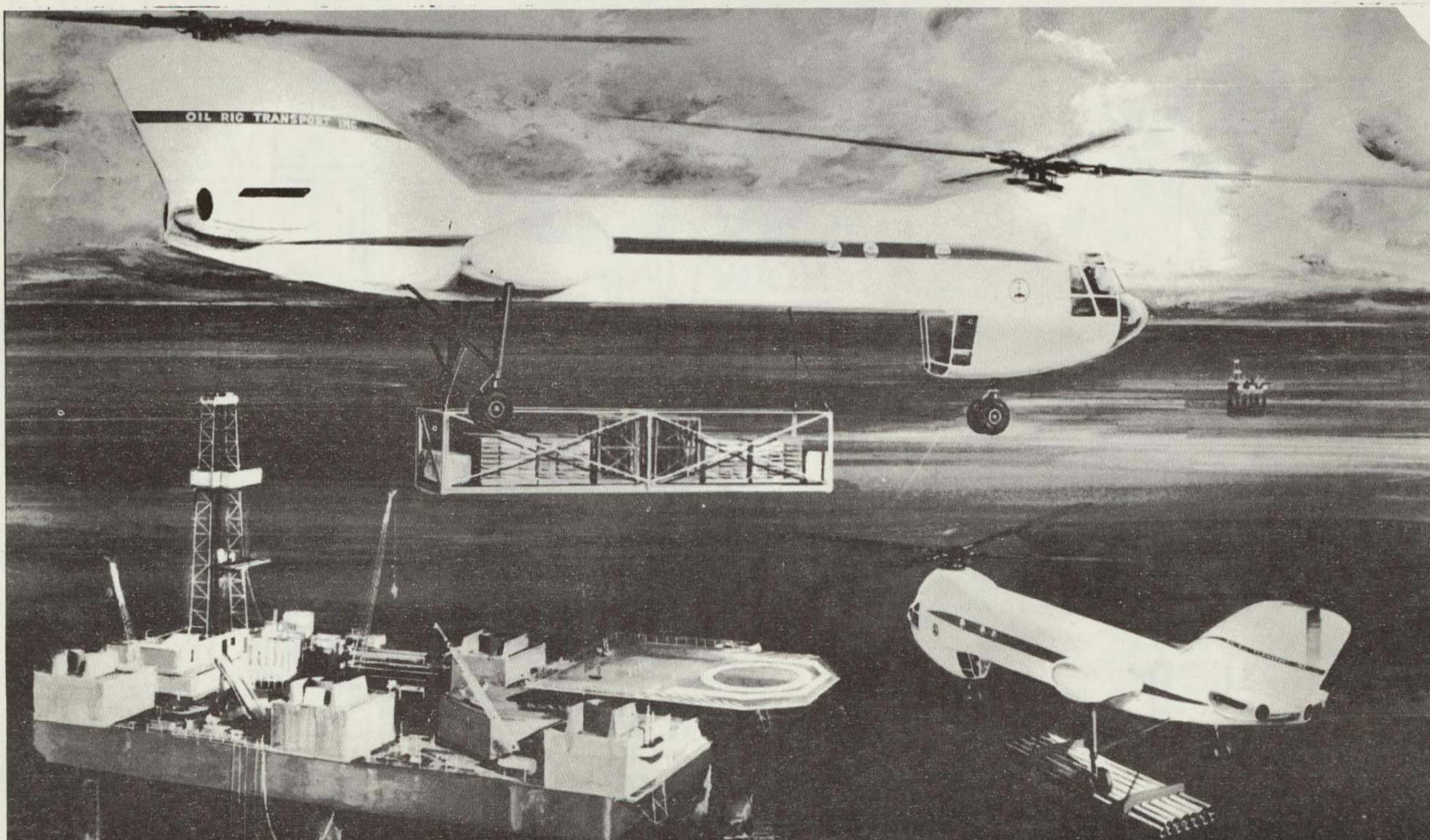


FIGURE IX-10

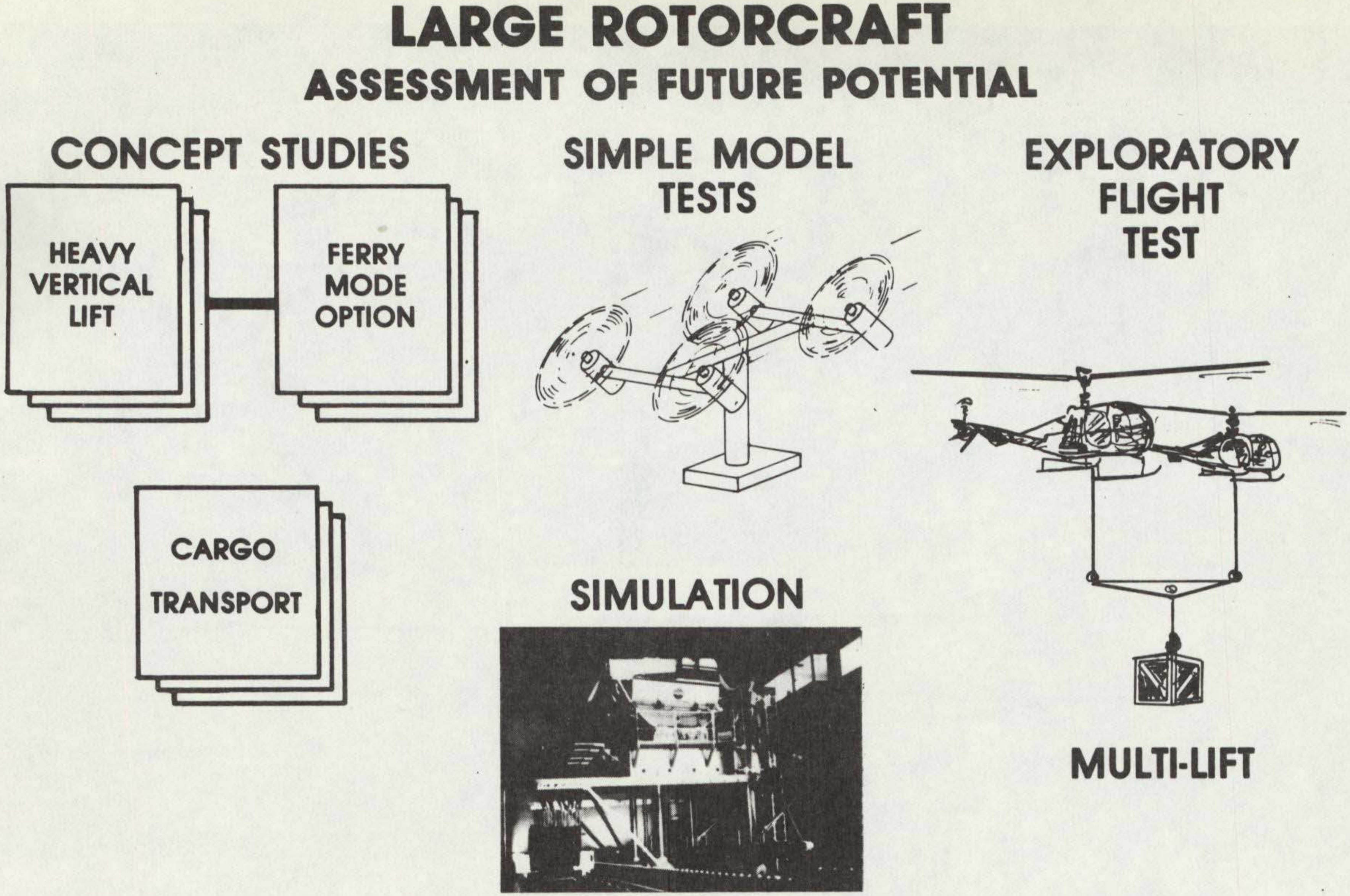

LARGE ROTORCRAFT
ASSESSMENT OF FUTURE POTENTIAL
CONCEPT STUDIES
HEAVY VERTICAL LIFT
FERRY MODE OPTION
CARGO TRANSPORT
SIMPLE MODEL TESTS
SIMULATION
EXPLORATORY FLIGHT TEST
MULTI-LIFT

FIGURE IX-11

XCH-62A DRIVE SYSTEM

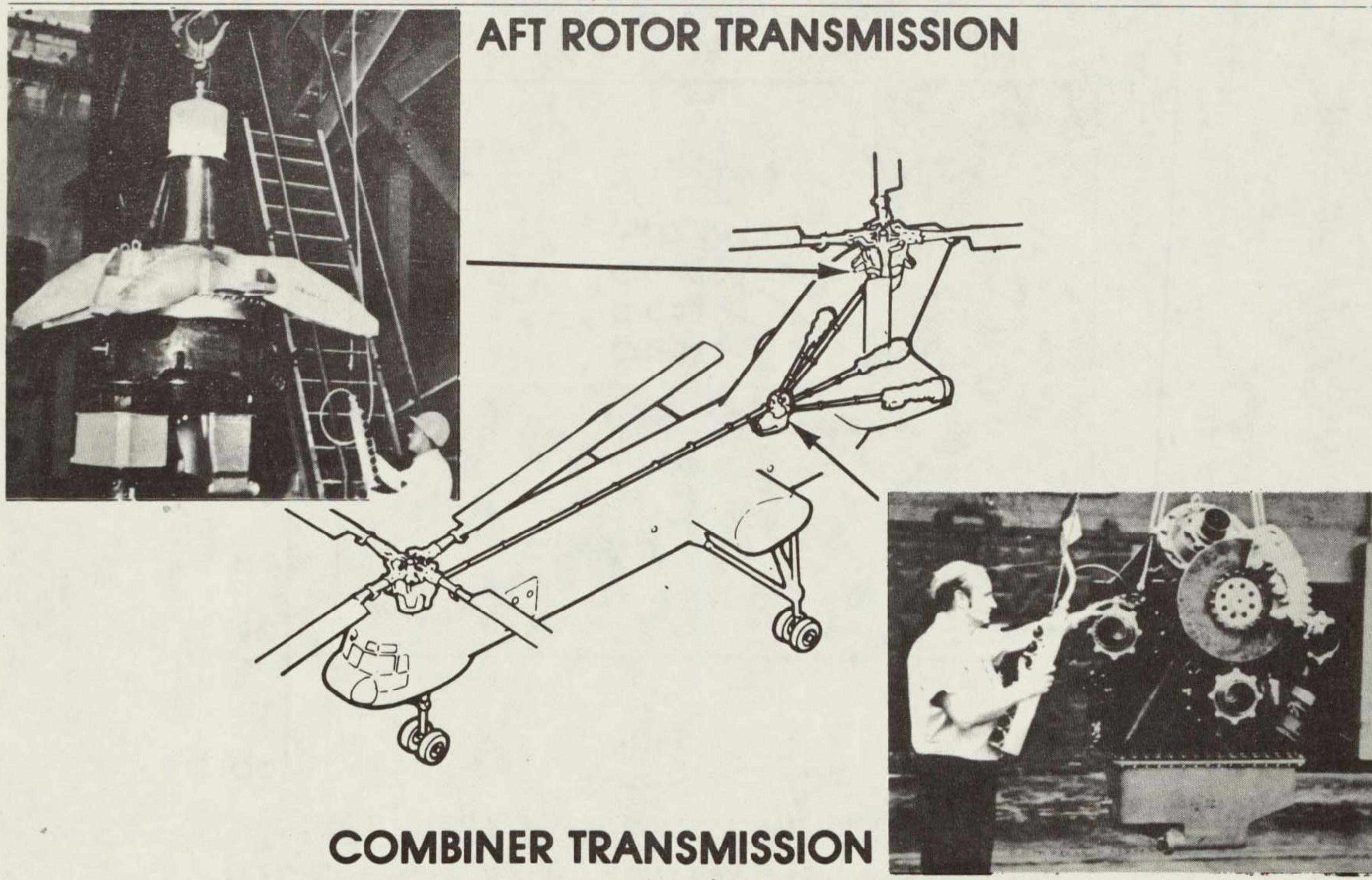


FIGURE IX-12

HELICOPTER TRANSMISSIONS
SIZE AND POWER COMPARISON

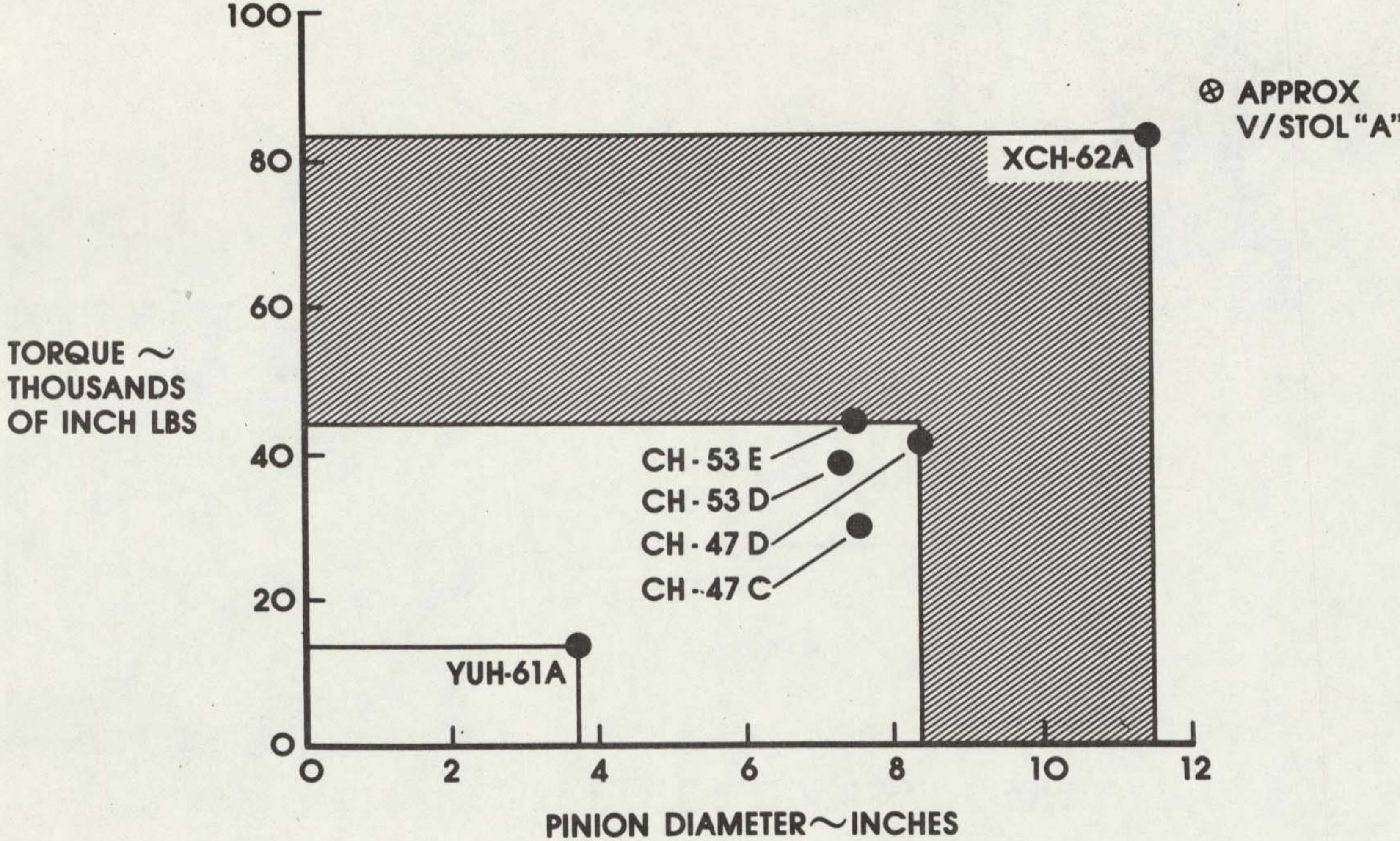


FIGURE IX-13

LARGE ROTORCRAFT
XCH-62A

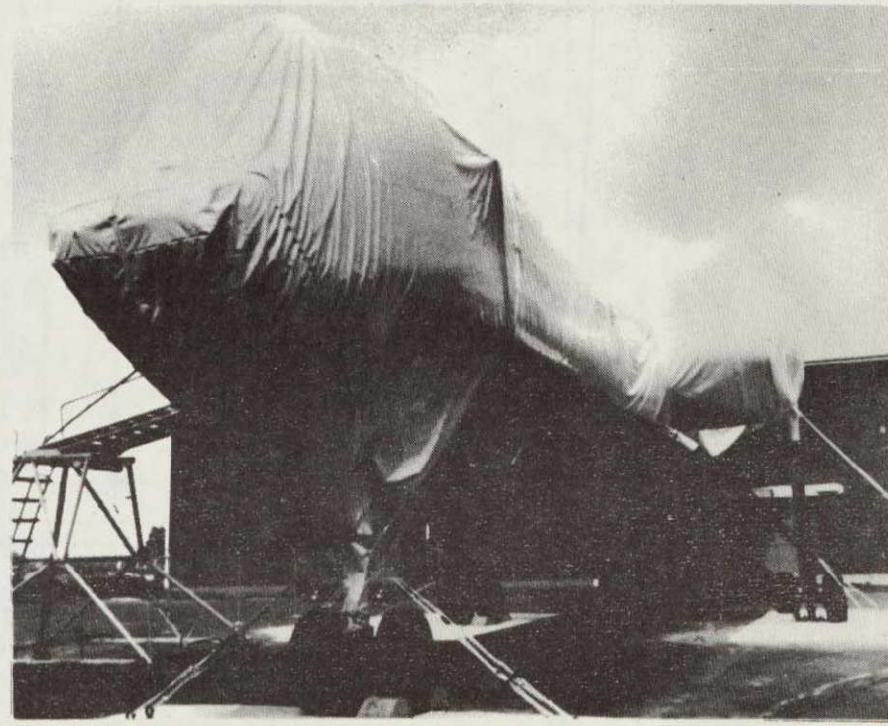


FIGURE IX- 14

LARGE ROTORCRAFT
SUMMARY

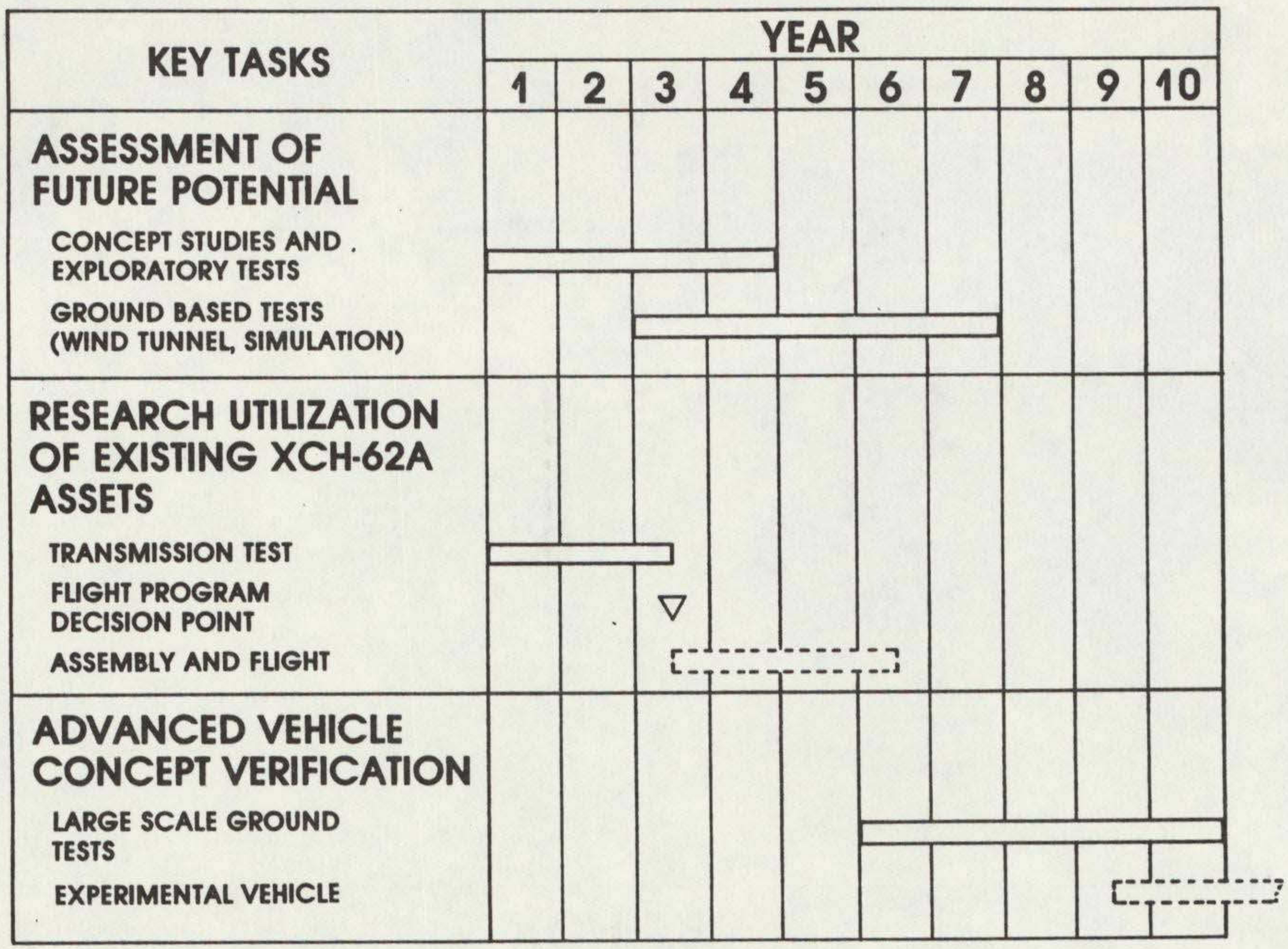


FIGURE IX- 15

PROGRAM RESOURCES

Table X-1 presents a summary of the estimates for the total 10-year funding that would be required to support the Advanced Rotorcraft Technology Programs categorized in the main thrusts of Aerodynamics and Structures, Flight Control and Avionic Systems, Propulsion, and Vehicle Configurations. An estimate of the total funding level for Future Options is also shown.

NASA's current commitment to the technology for rotorcraft is significant. The proposed program additions are being evaluated to determine how and to what extent the initial phases of the proposed program can be supported. Subsequent fiscal year funding needs will be considered as part of the agency budget preparation and will be determined in the budget development process.

TABLE X - 1

ADVANCED ROTORCRAFT TECHNOLOGY

PROGRAM FUNDING ESTIMATES

(In FY 78 Dollars)

TOTAL PROGRAMS	$398.1
Aerodynamics and Structures	132.5
Aero/Acoustics I	26.0
II	17.5
Vibration Reduction I	20.5
II	15.0
III	15.5
Composite Airframe I	13.0
II	25.0
Flight Control and Avionic Systems	85.1
All-Weather Systems	45.0
Active Control Systems	40.1
Propulsion	104.5
Engine Component Design Methodology	54.5
Power Transfer Technology	26.0
Systems Integration I	24.0
Vehicle Configurations	76.0
High Speed I	20.5
II	25.0
Large Rotorcraft I	12.5
II	18.0